AN INTRODUCTION TO TECHNICAL ELECTRICITY

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PUBLISHERS' NOTE

By the Education Act, 1918, provision is made for a large extension of the work of the Elementary School. Central Schools may be established in which, at appropriate stages, practical instruction suitable to the ages, abilities, and requirements of the better pupils must be given. Courses of advanced instruction for older pupils remaining at the elementary school beyond fourteen years of age must be provided, and measures taken for the preparation of those children who desire further education in schools other than elementary. It will be necessary also to arrange for a sufficient supply of continuation schools for young people between fourteen and (at present) sixteen years of age, the instruction in which must extend, within the working day, to 280 or 320 hours in each year, at the option of the local education authority.

A new type of book will be required for purposes of instruction in the new schools created by the Act; and the Life and Work Series is intended to supply it. The volumes in the series will be designed to satisfy two distinct ideals—one cultural and the other utilitarian or vocational—and in both cases the appeal will be through interest. It is not necessary to accept Rousseau's doctrine that a pupil should learn no lesson of which he does not feel the present need, yet he must

have a consciousness of value if a dynamic response is to be secured. While the aim of education is to train young people to be worthy and working members of the community, the immediate task of the teacher is to detect incipient growth towards the light and to encourage it.

Contact with life and work will, therefore, be the common bond of the series. Compulsory attendance at school may be prescribed, but compulsory attention must come from the pupil's own being, and it can be just as successfully and usefully stimulated by the wonders or achievements of science and industry as by masterpieces of art and literature. Interest in the principles and processes of daily work is as worthy as a regard for what are called cultural studies, and both will foster a desire for further knowledge. Citizenship implies not only duty towards life in the community but also efficient work on its behalf on the part of the individual. It is hoped that the volumes in this series will, by their close touch with reality, satisfy the vital needs of young students and provide the nurture and stimulus which are the essential functions of all educational effort.

PREFACE

THE study of Electricity may be approached in many ways; the usual, academic plan presupposes some knowledge of Mathematics, and follows approximately the historical development of the subject, beginning the study of electrostatics by rubbing amber with wool, of magnetism by an examination of the properties of lodestone, and of current electricity with an investigation of the voltaic cell. A second method regards the whole of Physics, including Electricity, as a convenient source of examples for the student of Mathematics with the result that many university students are introduced to Electricity first in connection with problems involving the equations of Laplace and Poisson. But such methods are quite unsuitable for young students of the kind to which the series of books, in which this volume appears, appeals.

Boys beginning active work in the world of industry must at the outset see some connection between their everyday occupation and the studies they are called upon to undertake. To arouse their intelligent interest, the appeal to them must be practical in character, and there is no reason why their study of Electricity, for example, should not begin with the construction of an electric bell or a small electric motor. In the present book the subject is developed from a study of the ordinary "dry" cell, which is easily procurable, and can be experimented with without

difficulty. From the beginning the various effects of an electric current and their important applications in industry are brought before the young student's notice. Simple experiments, precisely described, are introduced at every stage of the course, and the boy who follows the instructions will gradually secure an acquaintance with important electrical phenomena.

The knowledge of Mathematics required is of the simplest. The questions at the end of the chapters are intended as homework exercises for students attending a class, and will enable readers working alone to test their knowledge as they proceed.

The book is addressed to students who require instruction in Electricity of a practical kind and closely related to actual technical practice. If later they pursue their study of the subject they will have nothing to unlearn, and they will have learnt something of the intimate relation between the various applications of Electricity and the theories on which they depend.

I desire to tender my sincerest thanks to Sir Richard Gregory and to Mr. A. T. Simmons for the interest they have shown and the help they have given in the production of the book.

S. G. STARLING.

1920.

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CHAPTER I

ELECTRIC CIRCUITS

General considerations.—In approaching the study of electricity, it is well to obtain a clear idea of the properties common to all electrical appliances. If we consider the electric motor, telegraph, telephone, dynamo and lamp, we realise that there is one phenomenon common to all of them. This is called the **electric current**. It will be our object to examine the properties of this current, and to see how it causes rotation in the case of the motor, the reproduction of sound by the telephone, light in the electric lamp, and so on.

Source of current.—In the first place, there must always be some source to supply the current; because, whenever there is an electric current, work is continually being performed, and therefore energy is being used up to maintain the current.

When coal, or other fuel, is burnt, heat is liberated; and heat is a form of energy, that is, it has the capability of doing useful work when properly directed. The manner in which heat is used to convert water into steam under pressure, and the steam to move the piston in the cylinder of the steam-engine, which in turn drives the **dynamo**, must be studied elsewhere. The manner in which the rotating part of a dynamo gives rise to an electric current will be explained later. The dynamo

is mentioned here because it is the most important source of the electric current.

The source of current next in importance to the dynamo is the **electric cell**, or **battery**, of which there is a very great variety. There are also other sources but these are used very little.

Cells and batteries.—In the **electric cell**, the energy available for driving the current is due directly to a chemical reaction, generally the dissolving of the metal zinc in some acid. A zinc rod is immersed in a solution of sulphuric acid, or vitriol, in some cells; and in a solution of ammonium chloride, or sal-ammoniac, in others: but in both cases the zinc is eaten away, or dissolved, as the current is produced. This zinc rod is called the **negative pole** of the cell, and is usually connected to a screw terminal for the convenient attachment of the wire which conveys the current. The **positive pole** is, in many cells, a rod of carbon; that is, the hard compact residue left when gas has been distilled from coal. This gas carbon is cut, or compressed, into the rods employed in making electric cells. The positive pole is also connected to a screw terminal for the convenient attachment of the external wires.

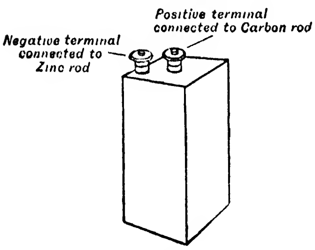

FIG. 1.—Electric cell

In Fig. 1 the general appearance of an ordinary cell, as used for telephones, electrical testing, etc., is shown. Its detailed construction will be explained in Chapter X. Such cells may be connected together to form **batteries**, when a greater effect is required than could be produced by one cell alone. The cells are generally square

in form so that they may be packed together conveniently when used in batteries. The proper method of connecting them together is shown in plan in Fig. 2.

The positive terminal is generally in the middle of the top of the cell and the negative terminal in one corner. In connecting the cells together, the **positive terminal of one cell must be connected to the negative terminal of the next,** and so on. The correct direction of twisting the wire round the screw of the terminal should be noted.

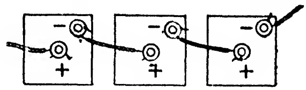

FIG. 2.—Battery of cells.

Effects of a current.—The two most important effects of an electric current are, its **magnetic effect** and its **heating effect.** There are some other effects which will be explained later, and still others which are of very little practical use. The magnetic effect will now be studied, as it is by means of this that the telegraph, telephone and other appliances are rendered possible.

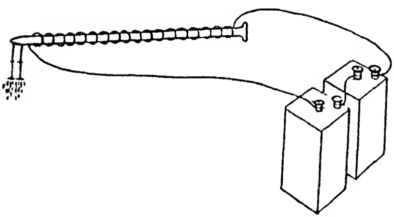

FIG. 3.—Magnetisation of iron by the electric current.

EXPT. 1.—**Magnetising effect of a current.**—Obtain a pair of dry cells, a foot or two of electric bell wire, and a piece of iron rod—a large nail such as is used by builders will do. Wrap the wire 30 or 40 times round the iron, and connect the bare ends to a battery consisting of a pair of dry cells, making the connections as shown in Fig. 2. The general arrangement can be seen in Fig. 3. Each wire must be bared at its ends, that is, the covering must be scraped off, leaving bare clean metal of sufficient length for the wire to be securely clamped in the terminal, with the metal of the wire in contact with the metal of the terminal.

Having completed the connections shown in Fig. 3, bring a few *iron* tacks, or *iron* filings, or any little pieces of *iron* or *steel* near one end of the rod. It will be found that they will cling to the iron rod.

On disconnecting the wire from *any one* of the battery terminals, the pieces of iron are no longer attracted and drop off the rod.

Magnetisation of iron by an electric current.—From this simple experiment a numbeı of facts may be learnt. In the first place, the iron rod has been changed from its ordinary condition by connecting the wires to the battery. We say that an **electric current is flowing in the wire,** and we see that when this current is flowing in the wire round and round the iron, the iron has the property of attracting other pieces of iron. It is said to be **magnetised.** This condition of magnetisation will be studied further in the next chapter.

The electric current requires a complete conducting circuit.—Expt. 1 showed us that the electric current ceases when one of the wires is detached from the terminal of the cell. It follows, therefore, that the current will only flow **when the metallic circuit is complete.** Metals are therefore said to be **electrical conductors.** All the metals are electrical conductors, and also some non-metals, such as carbon. One of the best conductors is copper. It is for this reason that **connecting wires** or **leads** are usually made of copper, although the copper is, in many cases, coated with tin, for the protection of the copper and to render the process of soldering more easy when making joints.

Insulators.—If the ends of the wire had not been bared in Expt. 1 before attaching to the cell terminals, no current would have flowed, showing that the current will not flow through the covering. Materials through which a current will not flow are called **insulators,** and it is necessary to cover the wires used to carry current, or to **insulate**

them, in order to make sure that the current shall not flow through an improper path, on account of the wires touching some other metallic body, or even each other.

Some of the best insulators are **air, amber, paraffin wax, india rubber,** and **silk**; and others, not quite so good, are dry wood and cotton.

Electric brake.—An application of magnetisation of iron by a current is seen in the electric brake used on trams. In Fig. 4 (*a*) a side view of such a brake is shown, and a section in Fig. 4 (*b*). The body of the brake consists of iron, and a coil of wire *A* carries the current which magnetises the iron. When the current is not on, the brake is just clear of the iron rails, but the current magnetises the brake which then clings to the rail. Owing to the force with which the brake is pulled on to the rail there is considerable friction between them. This form of brake is very powerful.

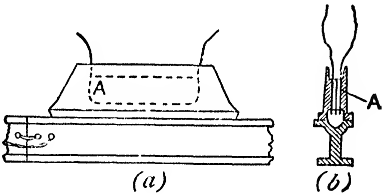

FIG. 4.—Electric brake.

EXERCISES ON CHAPTER I.

1. Describe briefly what is meant by an electric current.

2. Mention several sources of electric current, and state the purposes for which they are suitable.

3. Show by a diagram how you would connect four cells to form a battery to drive a current through a coil of wire.

4. Explain the difference between a magnetised and an unmagnetised piece of iron wire.

5. What is the distinction between an electrical conductor and an insulator? Why are the wires used for electrical purposes usually covered with an insulating material?

6. Describe some practical application of the magnetisation produced by a current in a coil of wire.

CHAPTER II

APPLICATIONS OF MAGNETISM

Iron and Steel.—There are many differences between iron and steel, one of the most important being that steel can be **hardened** by being made red hot and then cooled rapidly by being plunged in water. Hardened steel, when magnetised, retains its magnetism and is difficult to demagnetise ; but soft iron, although easier to magnetise than steel, readily loses its magnetism when the cause of it ceases to act.

EXPT. 2. **Distinction between iron and hard steel.**—Repeat Expt. 1 with this difference, that instead of a piece of iron, a steel rod, such as a knitting needle, is used ; or, better, several knitting needles are taken together in a bundle, and the insulated wire is wrapped round them. The experiment is performed as before, the steel becoming magnetised. But on disconnecting the wire from the battery the little pieces of iron do not drop off. The steel is said to be **permanently magnetised**. No magnetisation is absolutely permanent, since every movement, particularly hammering or vibration, causes its loss to a small extent, but good hard steel will retain its magnetism for a long time.

Permanent magnets.—There are many purposes for which **permanent magnets** are required, for example, bar magnets and horse shoe magnets (Fig. 5) are required for experimental work, compass needles for the magnetic

compass, and field magnets for magnetos, small dynamos, galvanometers, ammeters and voltmeters. The best steel for these magnets contains a small amount of the metal **tungsten,** and is called **tungsten steel.** It must be hardened by heating to a bright red heat (about 1000° C.) and then be plunged into water. This process makes it so hard that an ordinary file will not scratch it, and if its shape is to be changed, this must be done by grinding on an emery wheel.

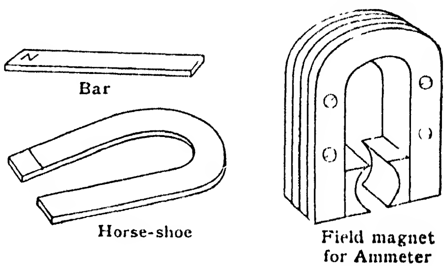

FIG. 5.—Permanent magnets.

The field magnet for a magneto, or ammeter (Fig. 5), is generally provided with soft iron pole pieces, which have a cylindrical space between them. The reason for this will be described later. It is customary to build such magnets up in layers, as in this way a higher degree of magnetisation can be obtained than if they were made of one solid piece.

Electro-magnets.—In Expt. 1 (p. 3) a very simple form of magnet was constructed, in which attraction between a piece of soft iron and some small pieces of iron was obtained. This arrangement is called an **electro-magnet,** and it has many applications. The shape of the magnet, the number of windings, and the current employed depend upon the use to which the electro-magnet is to be put.

EXPT. 3.—**Construction of an electro-magnet.**—A simple form of electro-magnet, of considerable attracting power, may be made by bending a piece of soft iron rod of about half to one centimetre in diameter into the shape *ABC* shown in

Fig. 6. This constitutes the **core** of the magnet. If it is more convenient, the core may be made of a bundle of soft iron wires, cut to the appropriate length ; in fact, for some purposes, the stranded is more efficient than a solid core. Upon the core is wound a length of insulated copper wire, care being taken, that as the wire passes from one limb of the magnet to the other, it shall pass from front to back or from back to front of the magnet.

The choice of wire for the windings depends upon the source of current available. If a secondary or storage battery

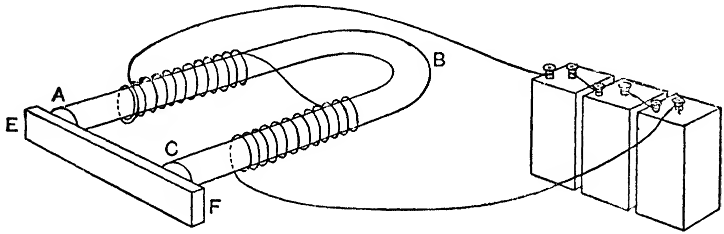

FIG. 6.—Simple electro-magnet.

(p. 112) is available, fairly thick wire (No. 18 or 20) may be used, and three or four layers will be sufficient ; but if dry batteries only are to be used, a finer wire, say No. 26, should be employed, and eight or ten layers wound on each limb. The wire must of course be covered. Cotton-covered wire is cheaper, but silk-covered wire is better. If cotton-covered wire is used, the coils may be made more durable by well soaking in shellac varnish. The insulating covering is necessary to prevent contact between neighbouring turns of the copper wire.

If the magnet is to be used for lifting weights, a soft iron bar, *EF* (Fig. 6), called an **armature**, should be made, which makes good contact with both poles.

Powerful electro-magnet.—In experimental work it is often desirable to use a very powerful electro-magnet. Such a magnet is illustrated in Fig. 7. The two limbs *AB* of the soft iron core are united at their bases by the

soft iron yoke *C*, and are provided at the top with two soft iron pole pieces *E* and *F*. Running through these are two cylindrical pieces of soft iron *G* and *H* with conical ends. These pieces can be clamped in any desired position by screws. If it is required to magnetise compass needles or to examine the magnetic properties of any substance, the body is placed in the gaps between *G* and *H*, where the magnetic field is very strong. A battery of many cells, preferably a storage battery (p. 112), is required to magnetise properly such an electro-magnet.

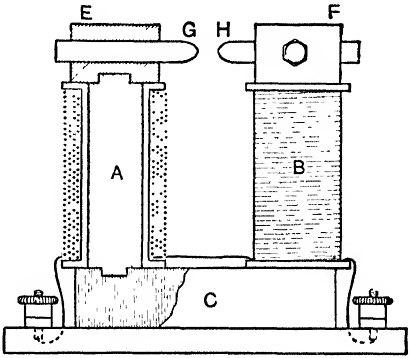

FIG. 7.—Electro-magnet.

Electric bell.—The ordinary electric bell or trembler is a good example of the employment of a simple electro-magnet. The bell is made in a great many patterns, and Fig. 8 shows the principle of them all. The electro-magnet *M* is small, and when the current passes in its coils, its soft iron core becomes a magnet and attracts the soft iron armature *G*. The magnetising current of *M* enters at the terminal *A*, passes through the spring *C* to the screw *S*, the end of which touches *C*. It then flows through the wire *E*, through the coil of *M*, and

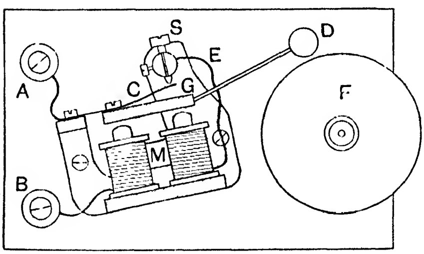

FIG. 8.—Electric bell.

so to the terminal *B*. On the current passing, *G* is pulled towards *M* and so the contact between *C* and *S* is broken, and the current stops. *M* ceases to be a magnet, and the armature *G* is pulled back by the spring *C* and contact is made again. The process is thus continued automatically. The distances of the parts are so adjusted that every time the armature *G* is pulled towards the magnet, the metal knob *D*, which is carried at the end of a stiff wire, strikes the gong *F*. The gong may therefore be struck a number of times per second, the number depending upon the stiffness of the spring *C* and the weight of the moving parts.

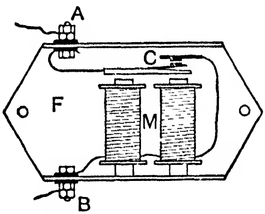

FIG. 9.—Electric buzzer.

Every time the contact between *C* and *S* is broken, a spark occurs at the break. If the surfaces in contact were made of iron or brass, these would soon wear away and the contact be spoilt. They should therefore be faced with *platinum*, because this will not wear away to nearly the same extent, since the platinum does not tarnish, and, further, the spark is smaller because the platinum has a very high fusing temperature.

Buzzer.—Unless a very loud sound is required, the gong of the electric bell is not necessary. The whole may then be made much smaller and a greater number of makes and breaks per second may be attained. The apparatus is then called a **buzzer**. Such buzzers are largely used for telegraphic signalling in the Army in conjunction with telephone sets, because the reaction to the key is very rapid, and a very sharp, high-pitched buzz can be obtained, so that the dots and dashes of the **Morse Code** (p. 13) are very clearly marked. The terminals *A* and

B (Fig. 9) are insulated from the brass framework *F* by small insulating washers. The current passes from the terminal *A*, through the spring and soft iron armature to the contact *C*. From there it is taken through the coils of the electro-magnet *M*, to the terminal *B*. There are many and more complicated patterns employed, but this serves as an illustration of the principle made use of in them all.

Simple telegraph.—By means of the buzzer (Fig. 9) or a sounder (Fig. 10), with a battery of a few cells and a

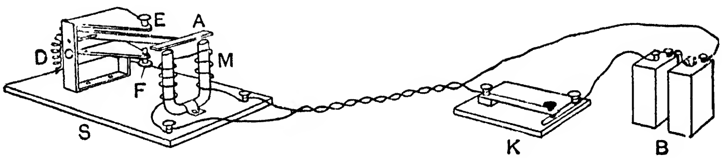

FIG. 10.—Simple electric telegraph.

key or switch, a simple telegraph may be constructed. The sounder consists of an electro-magnet *M* with a soft iron armature *A* (Fig. 10) carried by an arm *AB* pivoted at *C*. When there is no current, the spring *D* keeps the lever in contact with the upper stop *E*. When the current flows, *A* is pulled downwards, until the arm strikes the lower stop *F*, which is so adjusted that *A* does not quite touch the core of the electro-magnet. The reason for this is, that if it were to touch, then on stopping the current, the armature might still stick to the electro-magnet. If it does not touch, the spring *D* will always pull the armature up when the current stops.

There is a click when the arm strikes *F*, and another when it strikes *E*, and the interval between these clicks may be long or short according to whether a *dash* or a *dot* is intended. The whole apparatus *S* is called a

sounder and is situated at the **receiving station** of the telegraph.

At the **sending station** must be a key K and battery B, connected up as shown (Fig. 10).

The connection between the two stations is made by a long piece of twin wire, or if necessary, a single wire, using **earth** as the return path for the current. A good **earth** may be made by attaching a wire at each end, to a bare metallic water-supply pipe, or by means of an **earth pin**, which is a pointed iron rod about a foot long with a terminal at its upper end. The earth pin must be driven into the ground where the earth is moist. For communication between two stations it is of course necessary that there should be a sounder at each end and also a key at each station.

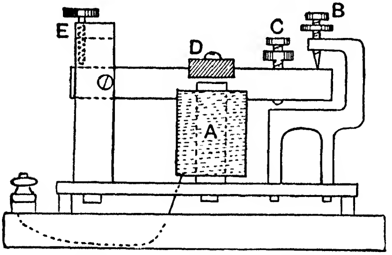

FIG. 11.—Post Office sounder.

In the Post Office, the sounder is used, as this can be employed for more rapid signalling than the buzzer, but it is more difficult to acquire skill in reading signals than is the case with the buzzer. In Army signalling the buzzer is employed, as the training required for the operator is not so great. Also the sensitiveness is in this case increased very much by the fact that an induction coil (p. 176) and telephone are used, so that the main current that works the buzzer does not require to be transmitted from one station to the other.

The sounder used in the Post Office is illustrated in Fig. 11. A is the electro-magnet, and D the armature. B and C are the screw stops for adjusting the travel of

the arm. The spring for raising the arm is not shown. When the current passes, owing to the pressing of the key at the sending station, *D* is pulled down by the electro-magnet, and the screw *C* makes a click on striking the metal bracket. When the current ceases, another click is caused by the arm striking the screw *B*. The interval between the clicks indicates the length of the dot or dash.

Morse code.—The code of signals used in signalling is the **Morse code**, which consists of a series of dashes and dots, each combination representing a certain letter or sign.

MORSE CODE.

		Numerals.
E .	*T* —	1 . — — — —
I . .	*M* — —	2 . . — — —
S . . .	*O* — — —	3 . . . — —
H		4 . . . . —
A . —	*N* — .	5 . . . . .
U . . —	*D* — . .	6 — . . . .
V . . . —	*B* — . . .	7 — — . . .
W . — —	*G* — — .	8 — — — . .
C — . — .		9 — — — — .
R . — .	*K* — . —	10 — — — — —
L . — . .	*Y* — . — —	
F . . — .	*Q* — — . —	
P . — — .	*X* — . . —	
J . — — —		
Z — — . .		

In addition to the above signs, there are others representing stops and various official instructions, but as these differ among the various services they are not given here.

EXERCISES ON CHAPTER II.

1. Describe simple experiments by means of which you would show the difference in magnetic properties between iron and steel.

2. How may a permanent magnet be made? Draw a sketch of some form of permanent magnet used in practice.

3. How does an electro-magnet differ from a permanent magnet? What is the most suitable material for the core of an electro-magnet? Give reasons.

4. Draw a sketch of an electro-magnet suitable for examining the magnetic properties of materials, showing the wiring.

5. Describe some form of electric bell or buzzer.

6. Sketch the connections of a simple telegraphic installation having one sender and one receiver.

7. Give the principle of the sounder used in telegraphy.

8. What is the Morse code, and how is it used in an electric telegraph?

CHAPTER III

MAGNETIC FIELDS DUE TO MAGNETS

Effects of magnets upon each other.—In Expt. 1 the effect of an electric current upon a piece of iron was observed, and in Expt. 2 the effect upon hard steel was seen. The iron or steel was said to be magnetised, and it is now necessary to examine this magnetic condition more carefully. In both cases the magnet attracts pieces of iron, but what its effect upon another magnet may be we must now find out.

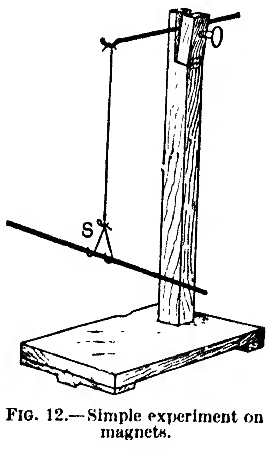

FIG. 12.—Simple experiment on magnets.

EXPT. 4—**Magnetic poles of a needle.**—Magnetise a knitting needle in the manner described in Expt. 2, and then suspend it by a fine silk thread; a single silk fibre is best. A stand as shown in Fig. 12 is very useful for this purpose, but if this is not available, the silk may be tied at its upper end to any support, which, however, *must not be made of iron or steel*. The needle may rest in a little wire stirrup *S*. It will be found that the magnetised needle **will only set in one direction**, and that this direction is nearly **north and south**. One particular end of the needle always points north and the other south.

On dipping the needle into iron filings it will be found that they only cling near its ends, or if tacks be used, they will only adhere near its ends.

Magnetic poles.—The ends of the magnetic needle are the only places where the magnetic effects can be observed, and these are called the **poles of the magnet.** That which points to the north is called the **north seeking** pole, or more shortly the N pole, and that which points to the south is the **south seeking** or S pole. In one respect both poles are alike, that is, they both attract iron filings, or any pieces of iron, but their difference is detected on suspending the needle, by noticing that one end always sets north and the other south.

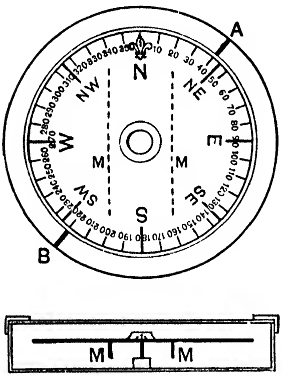

FIG. 13.—Magnetic compass.

Magnetic compass.—The property of a suspended magnet of setting roughly north and south has been known for a very long time, and has been used in navigation under the name of the **mariner's compass,** or more generally the **magnetic compass.** In Fig. 13 is shown a form of the compass used for rough surveying or for guidance in marching. A card is divided up by the cardinal points N, E, S, and W, other points being equally spaced between them. A scale of degrees should also be marked, beginning with 0° at the N and running round the card, 90° at E, 180° at S, and 270° at W, ending with 360° at N.

The compass card is provided at its centre with an agate cup which rests upon a steel needle, or better, a sapphire point. The card is balanced about this point so that it

sets horizontally. Two or more magnets *MM* are fixed to the card with the *N* poles both pointing the same way. When the card comes to rest the points of the compass indicate the bearings or directions of any distant objects. It should be remembered that the compass does not point true north. At the present time in England it points about 15° west of true north. The compass is provided with a glass lid upon which a fixed line is usually marked. A "lubber line" *AB* is marked on the case to facilitate the observation of a magnetic bearing by means of the compass.

Some simple forms of compass consist of a single magnetic needle supported on a point, the cardinal points being marked on the bottom of the box. To "set" a compass of this kind, the box is turned until the north point marked upon the box is under the *N* end of the magnetic needle; or more exactly, the *N* end of the needle must be over a point which is 15° west of the north point on the box, if the compass is "set" in this country, or by an appropriate amount if "set" elsewhere.

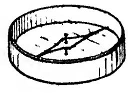

FIG. 14.—Charm compass.

A still more simple form, sometimes called a **charm compass**, such as is worn on the watch chain, consists of a little box with glass top and bottom, and a needle pivoted between the two (Fig. 14). Such a compass is very useful in examining the properties of magnets. The appropriate pole of the needle is marked *N*, or the *N* pole is indicated by an arrow head.

Forces between poles.—After having magnetised a knitting needle, as described in Expt. 2, the needle may be brought near a magnetic compass, or near another such needle, suspended as in Expt. 3. It will then be seen that if the *N* pole of the needle be bought near the compass,

it attracts the S pole of the compass and repels its N pole. On the other hand, if the S pole of the needle be brought near the compass, the N pole of the compass is attracted and the S pole repelled.

We thus see that

a N pole repels a N pole and attracts a S pole,
a S pole repels a S pole and attracts a N pole,

or, putting it in a slightly different manner,

Like poles repel each other,
Unlike poles attract each other.

Expt. 5. **Forces between poles.**—Set up the suspended magnetised needle as in Expt. 4, noting which end is the N pole, and marking it either with a file or by putting a small piece of paper on it. Now remove the needle and put another in its place, and mark its N end as before. Bring the N pole of the first needle near the N pole of the suspended needle and note what happens. Bring it near the S pole and note what happens. Repeat with the S pole and record the results as follows:

Pole of suspended needle.	Pole of applied needle.	Result.
N	N	Repulsion
S	N	
N	S	
S	S	

Instead of the suspended needle, a magnetic compass may be used if desired.

Iron or steel near a magnet.—It has been described how a piece of iron or steel may be made into a magnet by means of an electric current (p. 3). We shall now see that the iron or steel may also be magnetised by bringing it near a magnet. The strength of magnetisation

depends, of course, upon the nearness of the magnet and also upon its strength. For obtaining the greatest strength of magnetisation possible an electro-magnet (Fig. 7) may be used, but for examining the laws governing this effect, a fairly strong bar magnet (Fig. 5) will do. It will be found that **the part of the iron or steel which is nearer to the magnet becomes a pole of opposite kind to that near which it is placed.**

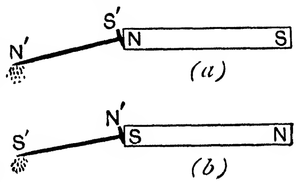

FIG. 15.—Magnetising by a bar magnet.

EXPT. 6. **Magnetisation by means of a magnet.**—Take a piece of soft iron wire—a 2-inch iron nail will do—and place it with one end in contact with the *N* pole of a bar magnet (Fig. 15 (*a*)). Bring some iron filings or tacks into contact with the end of the nail. It will be found that the end is a magnetic pole. Further, on bringing a compass needle near the nail, it will be seen that the distant end of the nail is a *N* pole, as at *N′*, and the near end will therefore be a *S* pole as at *S′*.

On repeating the experiment, using the *S* pole of the bar magnet, it will be found that the magnetisation of the nail is as shown in Fig. 15 (*b*).

On removing the magnet, the nail ceases to show any appreciable magnetic effect.

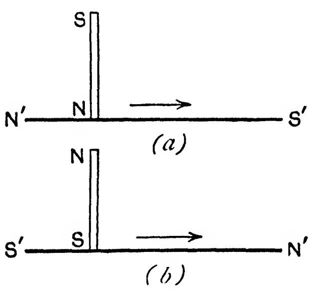

FIG. 16.—Magnetising by stroking.

EXPT. 7. **To magnetise a steel needle.**—If a piece of steel such as a sewing needle, or a knitting needle, is used in Expt. 6 it will be only feebly magnetised. In this case it is necessary to bring **every part of the needle** in turn near the magnetising pole. In order to do this, stroke the needle from one end to the other with the pole of the magnetising magnet. If this is done with the *N* pole, the magnetisation produced in the

needle will be like that shown in Fig. 16 (*a*); if the *S* pole be used it will be as shown in Fig. 16 (*b*). In either case **the place at which the stroking ends will be a pole of opposite kind to that with which the needle is stroked.**

The needle is found to be **permanently magnetised**. Its polarity can be reversed by stroking in the same direction with the opposite pole, or with the same pole in the opposite direction, but the magnetisation cannot easily be destroyed except by heating to red heat, which of course destroys also the hardness of the steel.

Force between iron or steel and a magnet.—The reason for the attraction between a magnet and pieces of iron can now be seen. On bringing the iron near the magnet, it becomes a magnet itself, the near part being an **opposite kind** of pole to that which it is near (Fig. 15). Now poles of opposite kinds **attract each other** (p. 18). Therefore the **iron and the magnet always attract each other.** This may be seen by bringing a piece of soft iron near a compass needle. The iron always attracts the pole near which it is placed, the reason being that it becomes a temporary magnet, having such a pole near the compass that attraction always takes place.

If, however, a piece of steel be used, the likelihood is that it is magnetised already and either end will **attract** one of the poles of the compass needle and will **repel** the other. If the steel is not previously magnetised, there will be an attraction by all parts, but this will not be so strong as in the case of the soft iron, because of the difficulty of magnetising the steel.

Magnetic fields.—The experiments described up to now have illustrated the fact that, surrounding an electric current, and surrounding a magnet, there is a space throughout which peculiar effects, which have been called magnetic effects, are capable of being exhibited. This space is sometimes called a **magnetic field**, and we may say, that

in a magnetic field, pieces of iron and steel become magnets, and magnets tend to set in a particular direction. Thus, the earth possesses a magnetic field, because a magnet, if freely suspended, sets in a given direction (p. 15). Also a piece of iron or steel may be magnetised by placing it north and south. If the piece is soft iron, it will be magnetised at once, but if of steel, hammering will assist its magnetisation. **The end which faces north becomes the N magnetic pole of the bar.** It should also be noticed that a vertical bar of iron becomes magnetised in a similar way, the **lower end being the N pole** if the bar is situated in the **northern hemisphere** of the earth and the **upper end the N pole** if in the **southern hemisphere**. This shows that the earth's magnetic field is in part vertical.

It is on this account that iron pillars and girders in buildings become magnetised. Likewise the iron and steel used in the construction of ships become magnetised, and consequently produce a disturbing effect upon the magnetic compass. This gives rise to many difficult corrections which must be made when navigating by means of the magnetic compass.

Magnetic lines of force.—There is a convenient and instructive method of representing magnetic fields. This plan consists in drawing lines in such a way that each line at each point of its path is in the direction of the magnetic field. Such lines are called **magnetic lines of force.**

Imagine a perfectly balanced thin compass needle. As it is perfectly balanced and free to turn, the only forces acting on it are those acting on its poles, due to the magnetic field in which it is situated. There is a force on its *N* pole in a certain direction, and another on its *S* pole in the opposite direction. As it is free to turn, it will come to rest with its length in the same

direction as these forces, that is in the direction of the magnetic field. If the suspended needle is short, it may be placed at different positions on a line of force and will always set along the line. Hence a line of force may also be defined as **a line which at every point has the direction in which a freely suspended small magnetic needle would set.** If such a freely suspended needle be placed in various positions near a bar magnet, the lines of force may be found to be shaped like the curve *AB* in Fig. 17. It is usual to consider a magnetic line of force to have the direction in which a **N pole is urged,** and to place an arrow on the line showing this direction. It will be seen that **magnetic lines of force arise on N poles and end on S poles.**

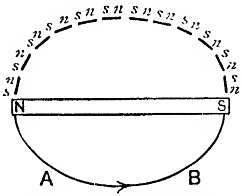

FIG. 17.—Magnetic lines of force.

EXPT. 8. **To plot magnetic lines ot force.**—Place a bar magnet on a sheet of paper and draw its outline. Divide its outline into equal parts by a number of points. Place a charm compass so that one pole comes to rest as near one of

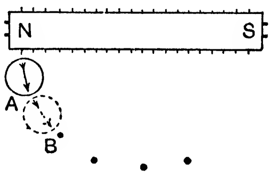

FIG. 18.—Plotting lines of force.

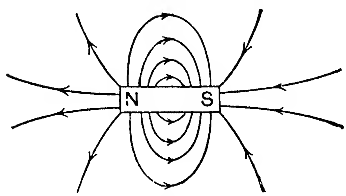

FIG. 19.—Lines of force of a bar magnet.

these points as possible, and make a dot *A* (Fig. 18) on the paper opposite the other pole. Remove the compass so that the first pole is over *A* and mark the second pole again *B*. Repeat this process until the chain of dots reaches the edge of the paper or returns to the magnet. Draw a smooth curve

through these points, and mark it with an arrow-head showing the direction in which the N pole of the compass points. Continue until every one of the points round the magnet is either the beginning or end of a line of force. The lines will be found to be of the form shown in Fig. 19.

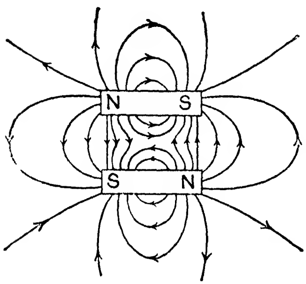

FIG. 20.—Lines of force of two bar magnets.

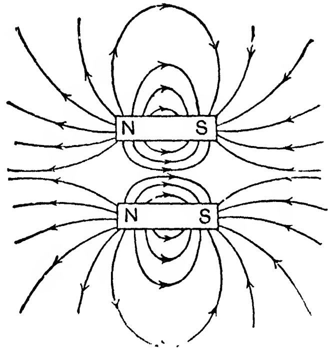

FIG. 21.—Lines of force of two bar magnets.

EXPT. 9. **Lines of force of two bar magnets.**—Using a pair of bar magnets, plot the lines of force by means of the compass as in Expt. 8. There are now two cases, namely that in which a N pole of one magnet is near a S pole of the other (Fig. 20) and that in which the N poles of both magnets are near each other (Fig. 21). The lines of force should be drawn for both cases.

EXPT. 10. **Lines of force for magnet and soft iron.**—Place a disc of soft iron near the end of a bar magnet and determine the lines of force as in Expt. 8. It will be noticed that the lines of force from the magnet are

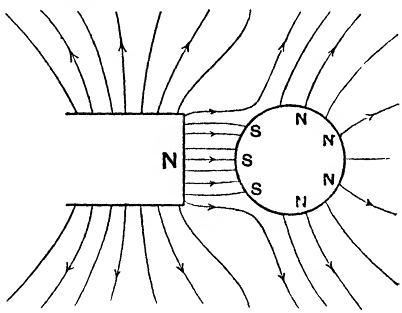

FIG. 22.—Lines of force for bar magnet and soft iron disc.

concentrated upon the iron disc, and from the direction of the lines it can be seen that the near part of the iron has magnetic pole of the opposite kind to that of the near pole of the magnet. This is in agreement with Expt. 6.

Plotting lines of force by means of iron filings.—There is a striking way of exhibiting the lines of force, which is not so exact as the method of plotting them point by point by means of a compass, but it is quicker.

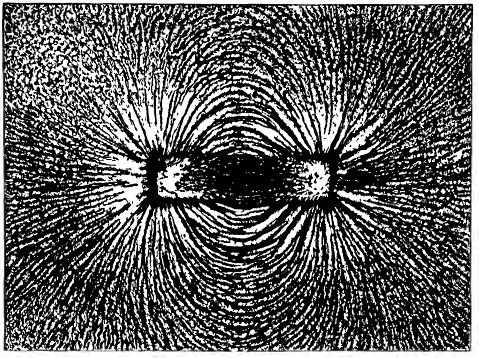

FIG. 23.—Lines of force by iron filings.

A sheet of paper or glass is placed over the magnet or magnets, and iron filings are sprinkled upon it. On tapping the sheet gently, the filings gather themselves into chains, and these chains, although irregular, are situated in the direction of the lines of force. Each filing, being situated in a magnetic field, becomes a magnet (p. 19) with its N pole pointing in the direction of the field and its S pole in the opposite direction. Then the N pole of one filing will cling to the S pole of the next, on account of the mutual attraction between opposite poles, and the chains of filings are thus formed. The poles of the magnet can be detected by the places

where the chains of filings are most thickly gathered together.

Expt. 11. **Lines of force by means of iron filings.**—Using

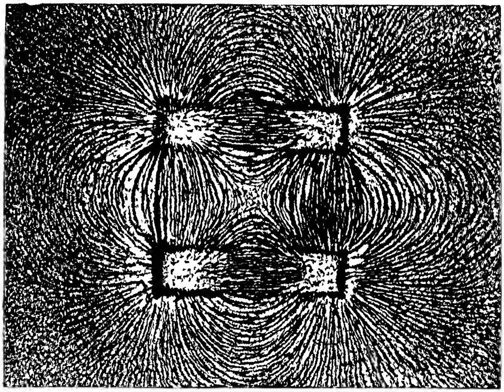

Fig. 24.—Lines of force; two bar magnets with unlike poles adjacent.

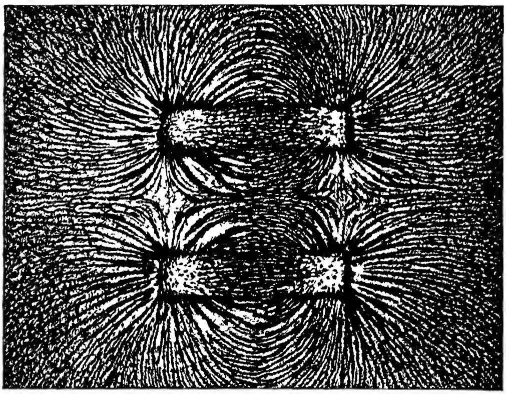

Fig. 25.—Lines of force; two bar magnets with like poles adjacent.

the same magnets as in Expts. 8, 9, and 10, obtain the lines of force corresponding to Figs. 23, 24, 25, and 26.

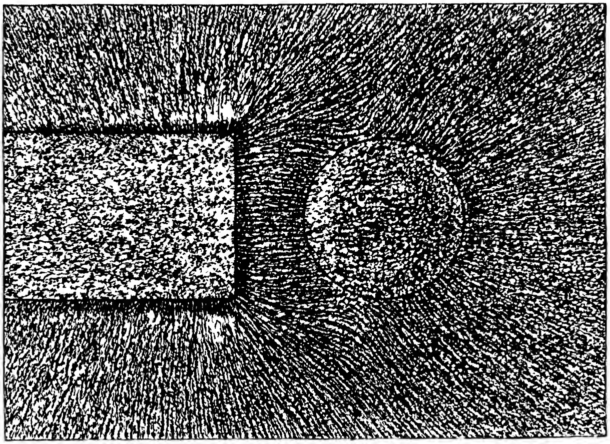

FIG. 26.—Lines of force; bar magnet and disc.

EXERCISES ON CHAPTER III.

1. Describe an experiment for finding the effect of one magnetic pole upon another, and give the law of force between poles.

2. What is a magnetic pole? How would you determine which is the *S* pole of a magnetised knitting needle?

3. Describe some form of magnetic compass, and explain briefly its use.

4. Explain how you would magnetise a knitting needle so that there is (*a*) a *N* pole at one end and a *S* pole at the other, (*b*) *N* poles at the ends and a *S* in the middle.

5. Why is it that a magnetic pole always attracts pieces of soft iron but may attract or repel any given piece of steel, according to circumstances?

6. What is a magnetic field? How do you know that the earth has a magnetic field?

7. What is a magnetic line of force? Draw the magnetic lines of force in the case of two parallel bar magnets with their like poles near each other.

8. Describe how a bar of soft iron may be magnetised in the earth's field alone.

9. A straight piece of soft iron wire which is unmagnetised is suspended by a silk fibre so that it rests horizontally. Will this wire set any particular direction? Give reasons for your answer.

10. A piece of soft iron of the same shape as a bar magnet is placed parallel to the magnet and with an air space of 2 centimetres between them. Draw the lines of force for such a case.

CHAPTER IV

MAGNETIC FIELD DUE TO CURRENT

Magnetic effect of an electric current.—It should now be clear that if a current and a magnet can produce similar effects, such as magnetising a piece of iron or steel, and in one case the effect is attributed to a magnetic

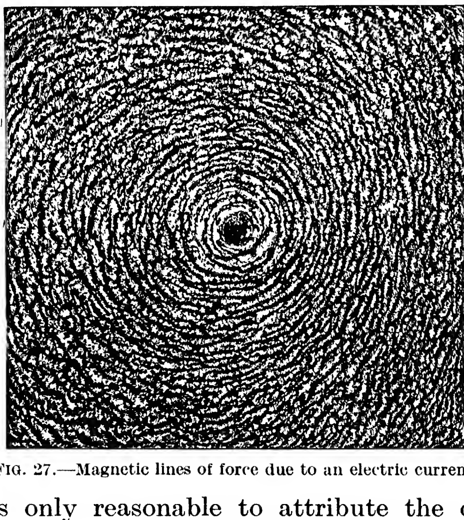

FIG. 27.—Magnetic lines of force due to an electric current.

field, it is only reasonable to attribute the other to a magnetic field. In the case of the electric current, the magnetic field which accompanies it can be represented by lines of force, just as in the case of that due to a magnet. The shapes of these lines of force must now be examined.

If a straight wire be passed through a sheet of paper, so that it is perpendicular to the paper, and a fairly strong current be passed through the wire, iron filings sprinkled on the paper take the form shown in Fig. 27. They are circles lying round the wire and having the wire as centre. Thus they do not begin on a *N* pole and end on a *S* pole as in the case of a magnet (p. 22), as there are no poles at all. Each line of force is a complete curve, without beginning or end.

EXPT. 12.—**Magnetic lines of force due to a straight current.** Join the terminals of a dry cell by a piece of fairly fine copper wire about a metre long. Place a small compass near a vertical part of the wire, and to the north of it (Fig. 28), and notice which way the *N* pole of the needle is deflected. Repeat with the compass south of the wire.

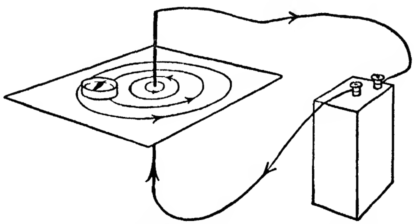

FIG. 28.—Drawing lines of force for a current.

Place the wire horizontal in a north and south direction and put the compass vertically over the wire, and note the direction of deflection. Repeat with the compass underneath the wire.

Observe that in all cases the motion of the poles of the compass needle is at right angles to the wire carrying the current. The needle will not always set at right angles to the wire because there is always the earth's magnetic field affecting it. It will be seen, however, that the force acting on either pole of the compass is always at right angles to the wire, and hence the magnetic lines of force due to the wire are circles having the wire as centre.

Also observe that the direction of the lines of force is in accordance with the **right hand rule** given below.

Right hand rule for the direction of current and magnetic field.—Hitherto no mention has been made of the direction

in which a current flows in a wire, or whether anything really does flow along the wire. This is a matter which in the present state of our knowledge is not clearly settled, but for convenience it is always considered that **the current leaves the battery by the positive (+) terminal and enters by the negative (−)**, as in Fig. 29. The magnetic lines of force then pass round the wire in the direction shown, which may be remembered by the right hand rule which is as follows—**If the wire be grasped in the right hand with the thumb pointing along the wire in the direction of the current then the fingers pass round the wire in the direction of the magnetic lines of force.**

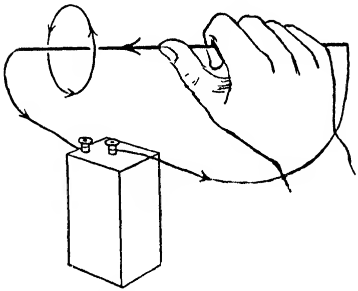

FIG 29.—Right-hand rule.

Lines of force due to a circular current.—Instead of the wire in Expt. 12 being straight, if it is bent into a circle, the magnetic lines of force are no longer circles. Their form, however, is of importance, and may be found, either by means of iron filings or by using a coil of the form shown in Fig. 30, and employing a small compass to obtain the lines. It will be noticed that near the centre of the coil, the lines of force are nearly straight lines, parallel to each other. This means that

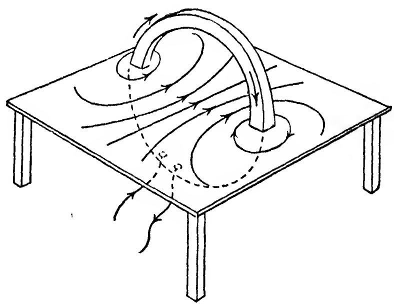

FIG. 30.—Lines of force due to a coil.

near the centre of the coil the field is uniform, for a **uniform magnetic field** must be represented by straight parallel lines of force, since the direction of the field is to be the same everywhere in it.

Expt. 13.—**Lines of force due to a circular current.**—Place drawing paper on the board of the apparatus shown in Fig. 30, cutting out holes for the coil to pass through if necessary. Pass a current through the coil. Take a series of points on a line joining the limbs of the coil, and, using a compass as in Expt. 8, draw lines of force.

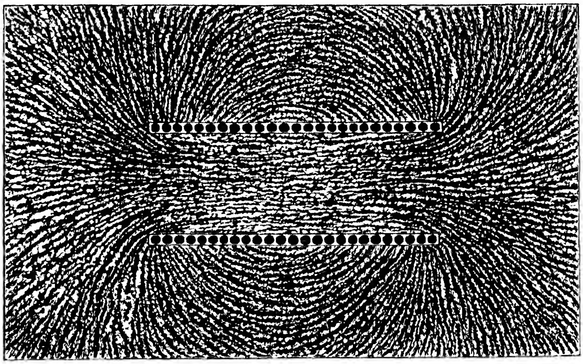

Fig. 31.—Lines of force due to a solenoid.

Solenoid.—A long uniform coil in which the wire lies in the surface of a cylinder is called a solenoid. In Figs. 3, 6, and 7 the coils are solenoids, although in the last two there are more than one layer. The magnetic lines of force due to a current in a solenoid are shown in Fig. 31. It will be seen, by comparing with Fig. 23, that externally the lines of force are very like those of a bar magnet; in fact, for points outside the solenoid, the magnetic effect is exactly like that due to a bar. But in the interior there is a difference, for it is seen in the case of the solenoid that the external lines are only the

continuation of those inside, and that for a considerable length of its middle part the **magnetic field is very nearly uniform.** This makes the solenoid a convenient arrangement for producing a uniform field. It is generally used when it is required to magnetise an iron bar strongly and uniformly. It has therefore a great many practical applications.

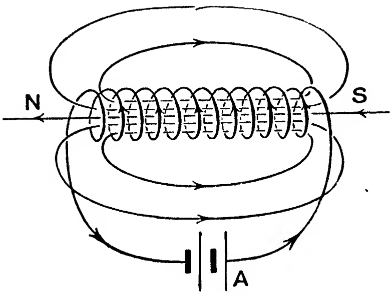

FIG. 32.—Magnetic field of a solenoid.

If the direction in which the current flows in the solenoid is known, it is easy to find by applying the right hand rule (p. 29) which is the N and which the S pole of the solenoid. In Fig. 32 the direction of the current is shown, and five magnetic lines of force are given. It should be noticed that the battery A of two cells is drawn in the conventional and convenient manner. The long stroke represents the positive terminal of a cell and the short stroke the negative terminal.

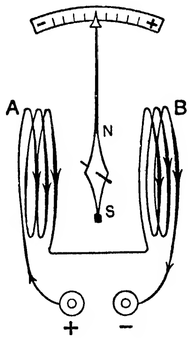

FIG. 33.—Simple current detector.

Current detector.—For the purpose of detecting a current, without requiring to measure it, a simple **detector** may be employed, consisting of several turns of wire AB, Fig. 33, with a pivoted magnet between them. On joining the terminal marked + to the positive terminal of a cell, the current flows as shown, and the N pole of the needle is deflected to the right. The needle is provided with a pointer which moves over a scale. This arrangement, although not

very sensitive, is convenient for discovering whether a cell has run down, or, when in doubt, which is the positive terminal. If the positive terminal were connected to the terminal of the instrument marked – the pointer would move to the left. The instrument

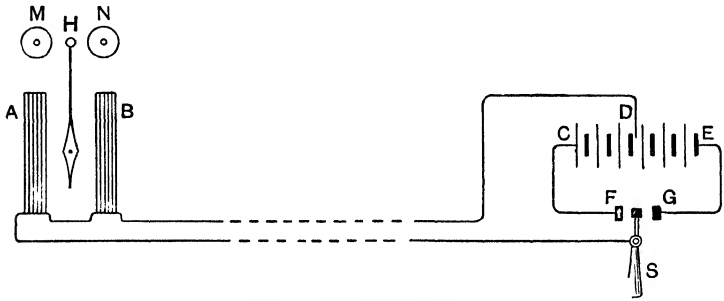

FIG. 34.—Railway telegraph.

may also be used in conjunction with a cell to find whether any conducting circuit is complete.

Railway telegraph.—A similar arrangement to the above is used on the principal railways as a telegraphic receiver. At the sending station, the switch handle *S* (Fig. 34) moving to the right makes contact at the left stop *F*, and enables the cells *CD* to send current to the receiving station, whereas if *S* moves to the left, contact is made at *G* and the cells *DE* are used. Thus the movement of *S* sends current one way or the other through the coils *AB*, and the magnet, which is provided with a little hammer *H*, moves one way or the other and strikes the gong *M* or *N*. These gongs have different sounds, which correspond to the dashes and dots of the Morse code (p. 13).

EXERCISES ON CHAPTER IV.

1. What is the shape of the magnetic lines of force due to a current in a straight wire? How would you show this?

2. If it is known that a current is flowing in a wire, the ends of which are out of reach, how can the direction of the current in the wire be found?

3. What is meant by a "uniform" magnetic field? How may a uniform magnetic field be produced?

4. Describe some form of current detector, and state two of its uses.

5. Explain how the principle of the current detector may be used in telegraphy.

6. Describe how you would investigate the direction of the magnetic field due to a battery of which the positive and negative poles are marked.

7. What is a solenoid? Trace by means of diagrams the similarity in magnetic effect of a bar magnet and a current flowing in a solenoid.

8. An electric current flows in a circle of wire which is placed vertically, and a short rod of iron is placed at right angles to the circle and at its centre. Sketch the magnetic lines of force of this arrangement.

CHAPTER V

MEASUREMENT OF CURRENT

Choice of unit of electric current.—The two most important effects of an electric current are, the magnetic effect which has been studied in the preceding chapters and the heating effect which will be described later. It is only by its effects that a current can be recognised, and we must choose some one effect by which to measure it. For reasons which cannot be given here, the magnetic effect is usually chosen for measuring current, the unit of current being one which produces a given magnetic field under specified conditions. This unit is called the **ampere**, in memory of the great experimenter A. M. Ampère, who first gave the exact form of the intimate relations between magnetic fields and electric currents. The relation of the ampere to the other electrical units will be given later.

Instruments for measuring currents.—Since an electric current is measured by means of the magnetic field which accompanies it, it follows that the current will be measured by a suitable arrangement for detecting and measuring the magnetic field. On p. 32 was described a simple form of current detector, and it will be seen that for a very small current in the coils AB (Fig. 33) the needle and pointer will not be moved, while for current which gradually increases, the deflection of the needle will first

become perceptible and will then increase. If then a scale is provided, over which the pointer moves, the strength of current can always be given in terms of this scale. If the current is required to be known in amperes, the scale must be **calibrated** by comparison with some standard instrument (p. 105).

There are two common types of instrument for measuring current, one of which is for measuring small currents such as are employed in electrical testing, and the other for large currents such as are met with in industrial work. The former are generally called **galvanometers** and the latter **ammeters.**

Galvanometers.—In designing a galvanometer for the detection and measurement of very small currents, several principles must be kept in view. The magnetic field due to the current in the coil disturbs a suspended magnet from its position of rest. It follows that for a given current, the field produced, and therefore the disturbance will be greater, the greater the number of turns in the coil in which the current flows. Also, it follows from common sense that the nearer the current is to the suspended magnet or needle, the greater will be its effect.

EXPT. 14. **Effect of a coil on a suspended needle.**—Obtain three circular coils of covered wire, *A* having one turn and radius 3 cm. (Fig. 35); *B* having ten turns of radius 3 cm., and *C* having ten turns of radius 6 cm. Connect the coils in series as shown, so that the same current flows in them all. At the centre of *A* place a small compass needle and turn the whole coil round until the needle is in the plane of the coil when no current is flowing. Put on the current and notice the angle through which the needle is deflected out of its original position. Now place the magnet at the centre of *B* and note that the deflection is much greater than when it is at *A*. Next place the compass at *C* and note that the deflection

is greater than when at A and less than when at B. This shows that the magnetic field is increased by increasing the number of turns and by diminishing the radius of the turn.

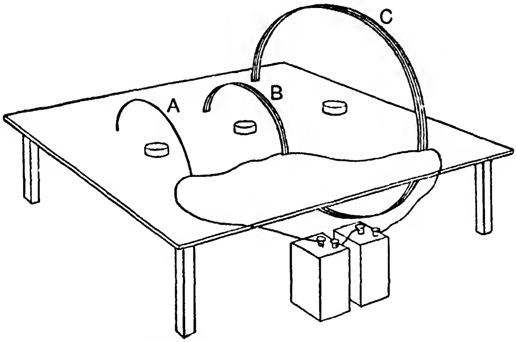

FIG. 35.—Effect of various coils on a magnetic needle.

Simple galvanometer.—The foregoing explanations indicate how a sensitive galvanometer may be constructed. When great sensitiveness is not required, the galvanometer may take the simple form shown in Fig. 36. For most purposes the coil need not be circular, and is here a flat coil of 20 or 30 turns. The suspended magnet is a short bar with a cup at its middle, in which is a hard stone, agate, which rests on a needle point, so that the magnet is free to rotate. A light pointer, consisting of a piece of fine wire or a piece of fine drawn glass tubing, is attached to the needle, so that by means of the circular scale, the deflection of the needle can

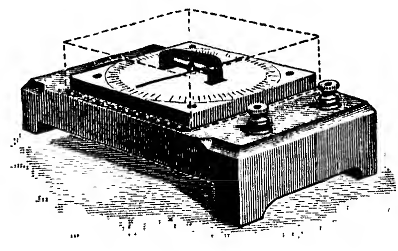

FIG. 36.—Simple galvanometer.

be observed. The ends of the coil are attached to the terminals, and a cover with a glass lid is usually placed over the coil to prevent disturbance by air draughts. A bar magnet placed on the table near the instrument may be used to bring the pointer to zero on the scale, and also to vary the sensitiveness of the instrument. This may be performed by trial. Such a magnet is usually called a **controlling magnet.**

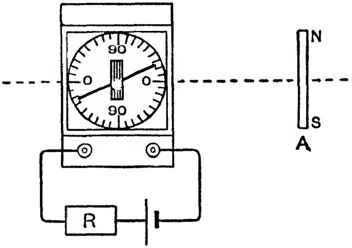

FIG. 37.—Use of a controlling magnet.

EXPT. 15. **Alteration of sensitiveness of galvanometer with a controlling magnet.**—Set up a simple galvanometer in series with a cell and resistance box *R* (p. 51), as in Fig. 37. With the current off, turn the galvanometer round until the pointer points to 0° on the circular scale. Pass the current and adjust the resistance *R* until the deflection of the pointer is 45°. Then stop the current and place a bar magnet at *A* with its middle point 40 cm. east or west of the centre of the galvanometer, and its *N* pole pointing north. Turn it about slightly until the pointer is again at 0° and put on the current. Note the deflection. Repeat with the magnet at 20 cm., and again with the magnet at 40 cm. and 20 cm., with its *N* pole pointing *S*. Tabulate the results.

It will be seen that with the *N* pole pointing north the deflection is increased; that is, the sensitiveness of the galvanometer is increased. With the *N* pole pointing south, the deflection is diminished and the sensitiveness is therefore decreased.

Force on a current due to a magnet.—Most modern galvanometers make use of the fact that when a wire carrying a current is placed near a magnet, a force acts upon it. This may be shown by bending a wire *ABCD*

into a rectangle and suspending it as in Fig. 38 so that a current can be passed round it. The suspension wires must be fairly fine so that the coil can turn. On bringing a bar magnet near the side AB this side of the coil will be driven to the right or left. CD would be driven in the opposite direction, and the other pole of the magnet will produce the reverse motions. AB is not attracted to or repelled from the magnet but is forced to one side.

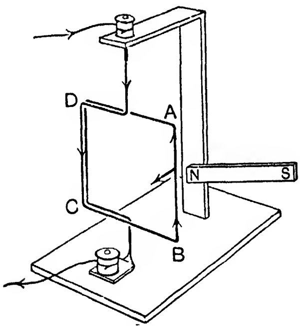

FIG. 38.—Magnet and current.

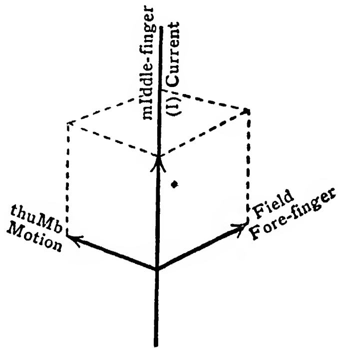

FIG. 39.—Left-hand rule.

It may thus be seen that **the force on an electric current in a magnetic field is at right angles to both the current and the field.**

EXPT. 16. **Force on a current in a magnetic field.**—Set up the experiment as in Fig. 38, and find the direction of the force of the N pole on AB and CD and of the S pole on AB and CD. Then reverse the current and reperform the experiment.

Left-hand rule.—Place the thumb, fore-finger and middle finger of the **left** hand mutually at right angles, that is, pointing along three edges of a cube as in Fig. 39.

Then if the

Fore-finger points along the Field,

and the **mIddle finger points along the current (I),**

then the **thuMb points in the direction of Motion,**

Suspended coil.—On taking a rectangular coil $ABCD$ (Fig. 40) and suspending it between the two strong magnetic poles N and S, and passing a current through it as shown, it follows, from the left-hand rule, that the side AB will be urged outwards as shown in the diagram, and CD inwards. The coil is therefore twisted, and the amount of twist will be greater with a strong current than with a weak one.

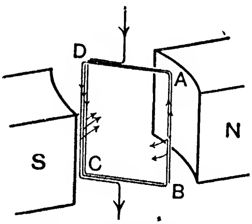

FIG. 40.—Rectangular coil in a magnetic field.

This arrangement is shown in a practical form in Fig. 41. The current is led in through the body of the powerful permanent magnet to the fine wire suspension F, which is usually a fine phosphor bronze strip. It then passes round the coil CC and out by the loose piece of strip G. There is usually a fixed soft iron cylinder A inside the coil, so that the sides of the coil move in the space between the poles N and S of the permanent magnet and the cylinder. The advantage of this arrangement is that the deflection of the coil is very nearly proportional to the current flowing in it, so that if we

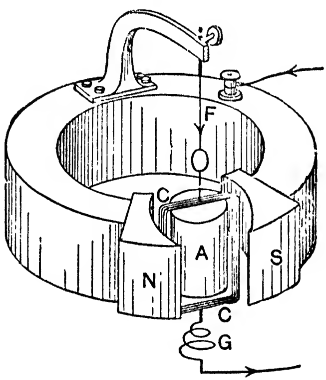

FIG. 41.—Suspended coil galvanometer.

know the current corresponding to one deflection we can calculate the current for any other deflection.

In some galvanometers, a pointer which moves over a circular scale is attached to the suspended coil, while in others a mirror is attached to the coil. A beam of light falls on the mirror and is reflected by it, and its movement is used to measure the deflection when great sensitiveness is required.

Ammeters.—When currents are to be measured in amperes (p. 35) a scale, suitably numbered, is provided, so that the reading gives the number of amperes flowing. In this practical form the instrument must be much less delicate than in the case of the galvanometer. The coil is provided with a pointer P (Fig. 42) and the movement of the coil is controlled by means of a fine spring S. Otherwise the construction is like that of the suspended-coil galvanometer. The spring S is also the conductor by which the current is led into the coil, and a similar spring underneath takes the current out.

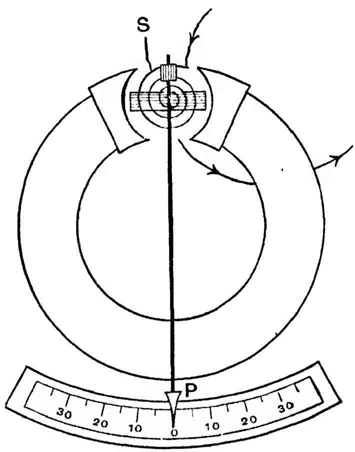

FIG. 42.—Milliammeter.

Ammeters have various ranges. Some read up to 1000 or more amperes, while others read up to 10 amperes, others to 1 ampere, and still others are used for very small currents. It is usual, when the current is very small, to read it in **milliamperes**, a milliampere being one-thousandth of an ampere. The instrument shown in Fig. 42 is a milliammeter. For still smaller currents

a **microammeter** is used. That is an instrument which reads millionths of an ampere. The suspended coil and spring of a milliammeter can be seen in Fig. 43, in which one pole piece of the permanent magnet is

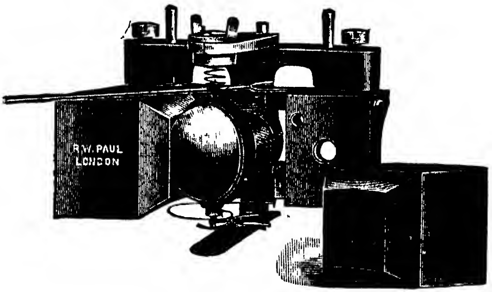

FIG. 43.—Pivoted milliammeter.

removed. In this case the coil is circular, and its weight is taken by a single pivot at the centre of the soft iron sphere. In instruments of the form given in Fig. 42 the coil is carried between two jewelled pivots.

Shunts.—Instruments like those of Figs. 42 and 43 will only carry weak currents. A strong current would overheat the coil and probably melt the spring. It would not be practicable to make a stout coil and spring to carry large currents, and consequently the device is used of passing only a part of the current to be measured through the instrument. In order to do this, the wires from the coil are connected to two terminals *A* and *B* (Fig. 44) on a thick metal strip. The current divides at *A*, the greater part going through this strip, and only a small fraction through the coil. Such a conductor is called a **shunt**. Once the fraction of the whole main

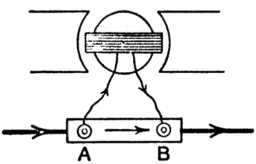

FIG. 44.—Shunt for an ammeter.

current passing through the coil is known, the instrument can be used as an ammeter, because this fraction will be the same for all currents. The use of a shunt has the great advantage that the instrument maker can design and make the moving coil part of the instrument in a standard form. When it is to be used for a low reading ammeter a thin and long shunt is used, but when for high currents, the shunt is a thick bar. Hence the shunt is the only part of the instrument that must be changed for making ammeters of various ranges. The ammeter is always standardised by comparison with a standard instrument after it is made.

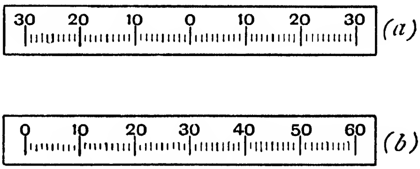

FIG. 45.—Types of scale for an ammeter.

Reference to Fig. 40 will show that if a current one way through the ammeter gives a reading to the right, a reverse current will give a reading to the left. For this reason some scales have the zero in the middle and read in both directions (Fig. 45 (*a*)). Others have the zero at one end and extend from left to right only (Fig. 45 (*b*)). In this case the current must always be sent the same way through the instrument, but there is the advantage of a greater range than in the former case. Also, a moving coil instrument can be used to determine which way the current is flowing. It follows that the instrument is useless for measuring alternating currents (p. 131), for in this case the current flows backwards and forwards many times a second.

Soft-iron ammeters.—There is another type of ammeter which is very convenient to use and cheaper to construct than the moving coil type. It was seen on p. 3 that a piece of soft iron is magnetised by an electric current

flowing in a coil, and on p. 18 that magnetic poles of the same kind repel each other.

The current is brought in at one terminal A, passes round a fixed coil C, and is led out by the terminal B (Fig. 46). E and F are two soft iron rods, E being fixed and F being part of a framework pivoted at G. With the current flowing as shown, E and F both become S poles, and therefore repel each other. This moves the pointer over the scale, which is graduated to read amperes. The other ends of the soft iron rods are both N poles, and their repulsion has the same effect as the repulsion of E and F. A small weight W attached to the moving framework enables fine adjustment to be made.

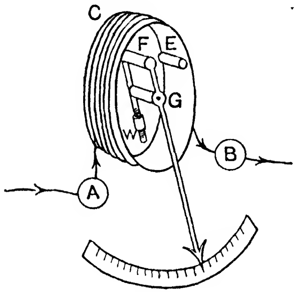

FIG. 46.—Soft-iron ammeter.

It should be noticed that if the current be reversed, all the magnetic poles are reversed. E and F are now N poles, so they still repel each other, and the direction of the deflection is the same as before. Hence the ammeter will measure alternating currents. For large currents the coil C consists of a few turns of thick wire, and for small current it has many turns of thin wire.

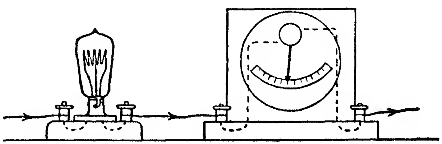

FIG. 47.—Use of an ammeter.

Use of an ammeter.—Ammeters are always placed in the circuit in which the current to be measured is flowing. This may make it necessary to break the circuit in order to put in the ammeter. Fig. 47 shows the way in which

the connections should be made. The dotted lines show the connections inside the instrument. This should be contrasted with the way in which a voltmeter is connected up (p. 71).

EXERCISES ON CHAPTER V.

1. State what you know concerning the ampere.

2. What is the distinction between a galvanometer and an ammeter ? Make a sketch of some form of simple galvanometer.

3. Give the important details for the construction of a very sensitive galvanometer.

4. Describe the use of a controlling magnet in connection with a galvanometer. Can such a magnet be used with a suspended coil galvanometer ?

5. Give the laws of the force upon a wire carrying an electric current when situated in a magnetic field.

6. Make a drawing of some form of suspended coil galvanometer.

7. Give a sketch showing how an ammeter is connected in circuit with a lamp, the current in which is to be measured. How may a milliammeter be converted into an ammeter.

8. Describe some form of soft-iron ammeter. For what purposes has it an advantage over the moving coil ammeter ?

9. How does the magnetic field at the centre of a circular coil change if (*a*) the current be changed, (*b*) the number of turns be changed, and (*c*) the radius of the circle be changed.

CHAPTER VI

HEATING EFFECT OF CURRENT

Heat produced in a wire.—The fact that an electric current in a wire is accompanied by the production of heat has already been mentioned (p. 3), and must now be studied more in detail. The amount of heat depends upon several things,—the strength of the current, the time for which the current flows, and the nature of the conductor in which the current is flowing. The dependence of the heat produced upon the time for which the current flows is fairly evident, for, other things being the same, the rate of production of heat remains constant, and in equal times equal amounts of heat are produced. It follows that the heat produced is proportional to the time for which the current flows.

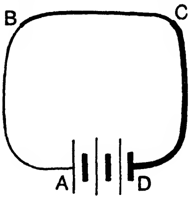

FIG. 48.—Various conductors and heating effect.

EXPT. 17. **Effect of conductor upon heat produced.**—In comparing the heating effects in different conductors, the same current must be used, as otherwise the difference in heating might be due to the variation in current. Therefore, take several pieces of bare copper wire, each about 20 cm. long, and connect them together as shown (Fig. 48), *AB* being fine wire, *BC* medium and *CD* thick, so that the same current flows in them all. Let them be joined to a battery of three or four cells, preferably storage cells (p. 112). On touching them by the hand it will easily

be seen that AB becomes the hottest, BC the next, and CD will probably not be appreciably warmed.

Repeat the experiment, taking three pieces of the same size, gauge No. 30 is suitable, but AB being copper, BC iron, and CD platinoid or german silver. It will now be found that CD is the hottest, BC next, and AB the least hot.

Resistance.—From the above experiment it may be seen that, for the same current, the finer the wire the more the heat produced in a given time. When the wire is very thick the heat produced is so small that it is hardly detectable, while, for a fine wire, the amount of heat for the same current and time is much greater. Also, different materials behave differently, more heat being produced in the iron than in the copper and more in the platinoid than in the iron. As the heating is the only detectable change in these wires, it follows that more energy is required to maintain the current in a fine wire than in a thick one of the same material. Or, it may be said that the thick one conducts the current more readily than the thin one. It is usually said that the thin wire has a greater **resistance** than the thick one, and an iron wire has a greater resistance than a copper wire of the same length and diameter.

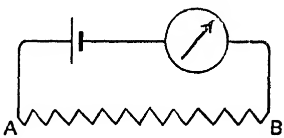

FIG. 49.—Variation of current with resistance.

A more exact definition of resistance will be given later (p. 48), but it may be noted that for given dimensions of conductor, the resistance is less when it is made of **silver** than of any other material. **Copper** comes next, and the other metals follow.

EXPT. 18. **Variation of current with resistance.**—Connect up in circuit a cell, a milliammeter, or some form of calibrated galvanometer and a piece of wire AB (Fig. 49). (a) Let AB

be a piece of fine copper wire (No. 36) 200 cm. long. Read the deflection. Then make AB 100 cm. long, and again read the deflection. It will be noticed that the current is nearly doubled. Now make AB 50 cm. long, and note that the current is again nearly doubled.

(*b*) Replace the No. 36 copper wire by a piece of No. 30 copper wire, and repeat (*a*). It will be noticed the similar relation between length and current holds, but that the currents are greater than in (*a*).

(*c*) Repeat with No. 30 iron wire, and note that the currents are less than with (*b*) although the same relation of current to length still holds.

Unit of resistance.—Although Expt. 18 does not definitely prove the fact, it may be recognised as probable that the current in a circuit is inversely proportional to its resistance, for it was seen that with decreasing resistance the current became greater. It is known from more exact experiments that in any circuit **consisting of metals, the current is inversely proportional to the resistance of the whole circuit.** Just as a unit of current had to be chosen, so a definite unit of resistance must be defined.

The unit of resistance used for practical purposes is the resistance of a **column of mercury** 106·300 cm. **long and weighing** 14·4521 **grams when its temperature is** 0° C. This unit of resistance is called the **Ohm.**

Although this is a good standard it is not very useful for practical purposes, and wires of resistance equal to 1 ohm are made in convenient form and can be bought from the instrument maker.

Conductors in series.—The most common method of arranging conductors in an electric circuit is to place them **in series.** In this arrangement the conductors are connected end to end, so that the same current flows in them all. Most of the preceding diagrams show conductors in series, but in Fig. 44 is seen another arrangement

which is described below. The conductors AB, BC, and CD in Fig. 50 are in series, and if their resistances

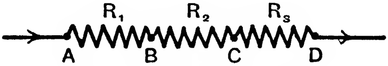

FIG. 50.—Conductors in series.

in ohms are R_1, R_2, and R_3, then the resistance of the whole conductor from A to D is the sum of these. Calling this R, we have,

$$\text{Combined Res. from } A \text{ to } D = R = R_1 + R_2 + R_3. \quad \ldots\ldots(1)$$

Thus, if AB is 5 ohms, BC 15 ohms, and CD 10 ohms,

$$\begin{aligned}\text{Resistance } AD &= 5 + 15 + 10\\ &= 30 \text{ ohms.}\end{aligned}$$

Conductors in parallel.—The other case of importance is that in which the conductors are joined **in parallel** as in Fig. 51. As the main current I arrives at one junction

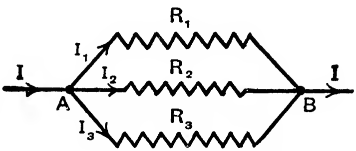

FIG. 51.—Conductors in parallel.

A, it divides, one part passing through each branch, and the parts unite at B, so that the current again becomes I. If I_1, I_2, and I_3 are the parts into which the current divides, of course,

$$I = I_1 + I_2 + I_3. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The rule for finding the combined resistance between A and B will not be proved here; it is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where R is the combined resistance. Thus, if

$$R_1 = 5,\ R_2 = 15,\ \text{and}\ R = 20\ \text{ohms},$$

$$\frac{1}{R} = \frac{1}{5} + \frac{1}{15} + \frac{1}{20}$$

$$= \frac{12 + 4 + 3}{60}$$

$$= \frac{19}{60};$$

$$\therefore\ R = \frac{60}{19} = \underline{3{\cdot}16\ \text{ohms.}}$$

Example.—The terminals of a cell whose resistance is 2 ohms are joined by three wires arranged as in Fig. 52. Calculate the resistance of the whole circuit.

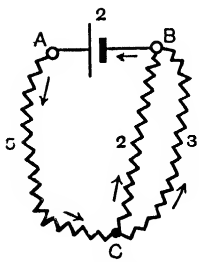

Fig. 52.—Problem

Notice first that the cell itself has a resistance. This is always the case, although the resistance of an accumulator is very small and generally may be neglected. Also that the two conductors between B and C are in parallel.

If then R is the resistance between B and C .

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{3} = \frac{5}{6};$$

$$\therefore\ R = \frac{6}{5} = 1{\cdot}2\ \text{ohm.}$$

Having found the resistance between B and C, the three conductors AC, CB, and BA are seen to be in series.

$$\therefore\ \text{Resistance of whole circuit} = 5 + 1{\cdot}2 + 2$$
$$= \underline{8{\cdot}2\ \text{ohms.}}$$

Example.—Six incandescent lamps are placed in parallel. If the resistance of each lamp is 180 ohms., what is the resistance of the six in parallel ?

Let R be the combined resistance of the six lamps in parallel, then

$$\frac{1}{R} = \frac{1}{180} + \frac{1}{180} + \frac{1}{180} + \frac{1}{180} + \frac{1}{180} + \frac{1}{180}$$

$$= \frac{6}{180};$$

$$\therefore \quad R = \frac{180}{6} = \underline{30 \text{ ohms.}}$$

Resistance coils.—For many purposes it is necessary to have conductors of known resistance. These are usually constructed by winding the wire on a reel or bobbin and soldering the ends to two brass terminals. The wire is silk-covered, and is usually of manganin or platinoid, or, for very good coils, platinum-silver. The required piece of wire is cut off a little longer than required, folded in two, and the fold screwed down to the shank of the bobbin as at S (Fig. 53). It is then wound double, and each end soldered to a terminal as at A and B. The length may be adjusted to the correct amount by softening one of the soldered joints and pushing the wire through. In order to preserve the coil it is usually soaked in melted paraffin wax, and afterwards placed in a protective case or wrapped round with silk ribbon.

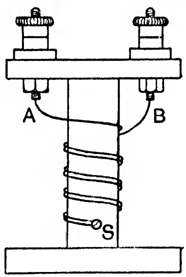

FIG. 53.—Resistance coil.

Resistance boxes.—In making up any required resistance by means of coils, it would be very inconvenient to have to join a number of coils together. It is therefore customary to make up **resistance boxes**, with the coils arranged in a decimal system like a set of weights. The

variety of arrangements is very great, but, as in Fig. 54, the coils are usually connected to brass blocks *ABCDE*. Brass plugs fit into holes between the blocks, so that any

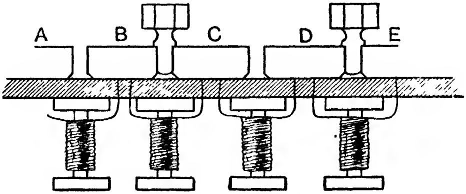

FIG. 54.—Construction of resistance box.

given coil can be cut out, that is the equivalent resistance reduced to zero by putting in the plug over the coil. The brass blocks are screwed on to a sheet of insulating

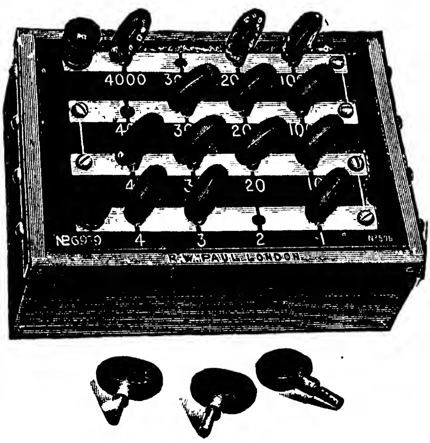

FIG. 55.—Resistance box.

matèrial such as ebonite, to which also the coils are attached.

The general appearance of a resistance box constructed on this principle is given in Fig. 55, in which the resistances are 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400,

1000, 2000, 3000, 4000. It can therefore be seen that any resistance from 1 ohm to 11110 ohms can be obtained by taking out the appropriate plugs.

Expt. 19. **To measure the resistance of an incandescent lamp.**—Connect the incandescent lamp in its holder, in series with a dry cell, a milliammeter or a simple galvanometer, and a resistance box as in Fig. 56. Put in all the plugs in the box so that its resistance is zero, and note the deflection of the galvanometer. If this deflection is too great, the

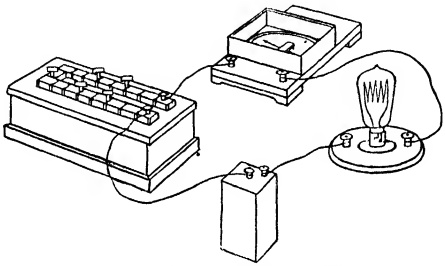

Fig. 56.—Measurement of resistance.

needle may be brought to a suitable position by means of a controlling magnet (p. 38).

Now take the lamp out of the circuit, joining the wires together where it was taken out, so that the circuit is again complete, but without the lamp. The deflection will now be very great, and it must be brought back to its original value by taking out plugs from the resistance box. When the deflection is restored to its previous amount, the current is brought back likewise, and therefore the resistance of the circuit is the same as before. Hence the resistance of the lamp, which was taken out of the circuit, is equal to the resistance in the box, which is known. In this way find the resistance of several incandescent lamps.

Rheostats.—When it is required to vary the resistance in a circuit to change or regulate the current, without requiring to know the value of the resistance, a **rheostat** is used. There are many forms of rheostat, but the most

common consists of a high resistance wire, generally platinoid, wound upon a rod or tube, and having a sliding contact to vary the number of turns of wire in the circuit. A simple and convenient form of rheostat is shown in Fig. 57. Two bars of slate *AB* and *CD* have wound upon them a length of platinoid wire of size depending upon the purpose for which the rhetostat is to be used. No. 22 is a convenient size for most purposes. Terminals *E* and *F* are attached to one end of each wire. The bridge *G* is a bent strip of brass which makes contact with the two coils of wire, so that the current follows the path *EGF*. On sliding *G* towards *BD* a greater amount of wire is included in the circuit, and the resistance is increased. On sliding towards *AC*, turns of wire are cut out of the circuit, and the resistance is reduced.

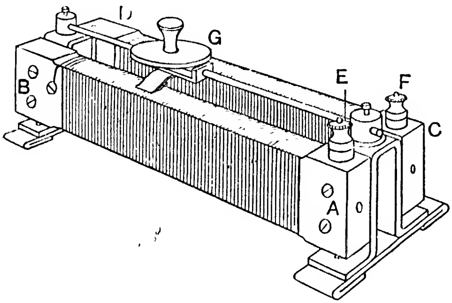

FIG. 57.—Wire rheostat.

Another useful form of rheostat consists of a number of carbon plates *C* between two brass plates *A* and *B*, provided with terminals (Fig. 58). The plates can be squeezed tightly together by means of the screw *S*. The resistance of the column of plates gets less as the plates are squeezed more tightly together, because their surfaces come

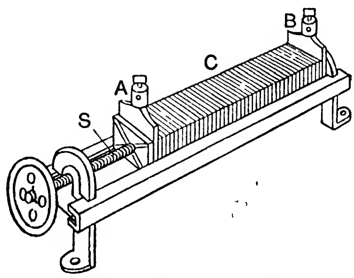

FIG. 58.—Carbon rheostat.

more intimately into contact with each other. Hence the resistance of the column may be varied by screwing or unscrewing the screw *S*. Carbon rheostats of this type are suitable when large currents are to be used, as a current of say 20 amperes can easily be carried by them, while such a current would burn out a wire rheostat of the type shown in Fig. 57.

Electromotive force.—Turning now to the origin of the heat produced in a conductor when a current is flowing, it is necessary to find some point in the circuit where change of some kind is going on. The only part where this is the case, so far as has at present been considered, is the cell, or battery. In Chapter X it will be seen that chemical processes continually go on in cells producing current, whereby energy is liberated, and this energy supplies the work for maintaining the current and producing the heat in the circuit. Further, it is common experience that a cell becomes "run down" or "used up" after a time, which fact clearly indicates that something in the cell, necessary for the production of energy and the maintainance of the current, has disappeared. The driving power of the current is therefore located in the cell or battery, and it is necessary to find out whether all cells have the same driving power, or as it is more properly called **electromotive force,** very frequently written **e.m.f.** for convenience. It is also necessary to find out how the electromotive force of a battery depends upon the number and arrangement of cells in it.

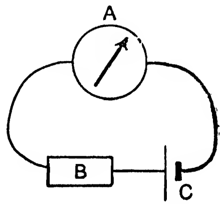

FIG. 59.—Effect of various cells.

EXPT. 20. **Electromotive force of different cells.**—Set up a circuit consisting of a galvanometer or milliammeter *A* (Fig. 59), a resistance box *B* and a cell *C* in series. In

the first case let the cell be a storage cell (p. 112). Unplug resistance in the box *B* until the deflection is about three-quarters of the whole scale of the galvanometer, and read the deflection. Then replace the storage cell by a Leclanché cell (p. 109) and again note the deflection. Repeat with a dry cell, and again with a Daniel's cell (p. 108). Make a table of the results. From this table it will be seen that the storage cell produces the greatest current and the Daniel's cell the least. Therefore the storage cell has the greatest electromotive force and the Daniel's cell the least.

EXPT. 21. **Electromotive force of a battery.**—Set up the arrangement of Expt. 20, but with 4 dry cells in place of the single cell *C*. Adjust the resistance in *B* until a reasonable deflection is obtained, and record the deflection. Remove one cell and record the deflection due to the remaining 3. Repeat with 2 cells and 1 cell. Make a table of the results, and notice that with increasing number of cells the current is nearly proportional to the number of cells.

Unit of Electromotive force.— It is not so easy to obtain a standard of electromotive force as it is to obtain that of current or resistance. For the present we will take the legal standard as that of a certain cell, constructed in a particular manner. The cell is called the **cadmium** or **Weston** cell (p. 112), and is made up according to a standard specification. Its electromotive force at a temperature of 20° C. is 1·0183 units. The name given to this unit is the **volt**, so that it may be said that the e.m.f. of the standard cell at 20° C. is 1·0183 volts.

Electromotive force, current and resistance.—It is clear from what has gone before, that the current in a circuit depends upon the electromotive force in the circuit and the resistance of the circuit. Although the method in which the volt, the ampere and the ohm have been derived is beyond the scope of this book, and belongs to more advanced study, it can be understood that these units have been chosen so that a certain simple relation

exists between the e.m.f., current and resistance in any circuit. This relation is:

$$\frac{\textbf{e.m.f.}}{\textbf{current}} = \textbf{resistance}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

or,
$$\frac{\textbf{e.m.f.}}{\textbf{resistance}} = \textbf{current}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

or,
$$\textbf{e.m.f.} = \textbf{current} \times \textbf{resistance}, \quad \ldots\ldots\ldots\ldots(6)$$

that is,
$$\frac{E}{I} = R, \quad \frac{E}{R} = I, \quad \text{or} \quad E = I \times R,$$

where E is the e.m.f. in volts, I the current in amperes, and R the resistance in ohms.

EXAMPLE.—A circuit is made up of a cell of e.m.f. 1·5 volt, and resistance 1 ohm, a galvanometer of resistance 4·5 ohms and wire of resistance 0·5 ohm, all in series. Find the current.

$$\text{Total resistance of circuit} = 1 + 4{\cdot}5 + 0{\cdot}5$$
$$= 6 \text{ ohms};$$

$$\therefore \text{ from equation (5), current} = \frac{1{\cdot}5}{6} = \underline{0{\cdot}25 \text{ ampere.}}$$

EXAMPLE.—What must be the resistance of a wire placed in circuit with two dry cells of e.m.f. 1·65 volts and resistance 0·5 ohm. each, and a galvanometer of resistance 10 ohms, in order that a current of 15 milliamperes shall flow in the circuit?

$$\text{Total e.m.f. in circuit} = 2 \times 1{\cdot}65 = 3{\cdot}3 \text{ volts.}$$
$$\text{Current in circuit} = 15 \text{ milliamperes}$$
$$= \frac{15}{1000} \text{ amperes};$$
$$\therefore\ 3{\cdot}3 = \frac{15}{1000} \times R \text{ (from equation (6))},$$

where R is the resistance of the circuit in ohms.

$$\therefore\ R = \frac{3{\cdot}3 \times 1000}{15}$$
$$= 220 \text{ ohms.}$$

But the galvanometer and battery have together a resistance of $10+2(0\cdot5)=11$ ohms.

$$\therefore \text{ Resistance of wire} = 220 - 11$$
$$= \underline{209 \text{ ohms.}}$$

Voltmeters.—Any apparatus for measuring electromotive force may be called a **voltmeter**. The commonest type of voltmeter consists of a galvanometer or a milliammeter with a suitable high resistance in series with it. Thus the instrument shown in Fig. 42 may be converted into a voltmeter. For, suppose the high resistance R (Fig. 60) to be placed in series with it, and that the resistance of the moving coil is 10 ohms, let us find what resistance R must have in order to make the instrument into a voltmeter.

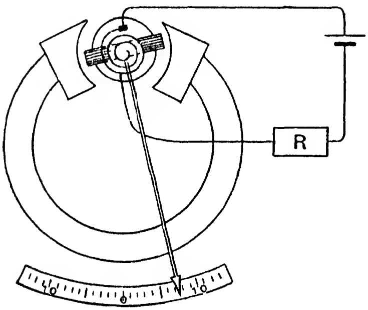

FIG. 60.—Voltmeter

Now 1 volt in the circuit is to produce a current of 1 milliampere, that is 0·001 ampere;

$$\therefore \text{ total resistance} = \frac{1}{0\cdot001}$$
$$= 1000 \text{ ohms.}$$
$$\text{But resistance of coil} = 10 \text{ ohms.}$$
$$\therefore \text{ Resistance } R = 1000 - 10$$
$$= \underline{990 \text{ ohms.}}$$

By choosing suitable values for R, any scale may be obtained for the instrument. As shown in Fig. 60, the readings are intended to indicate volts. Of course the resistance of the cell has been neglected, but the resistance

of the voltmeter should always be so high that the resistance of the other parts of the circuit may be neglected. This arrangement has the great advantage that the permanent magnet and moving parts of the instrument may be made of a standard form, and the resistance R varied so that the instrument will have any desired scale, say 0 to 1 volt, or 0 to 1000 volts. There are other voltmeters made on entirely different principles, but these cannot be considered here.

EXPT. 22. **E.M.F.'s of various arrangements of cells.**—Place a low reading voltmeter, or a direct reading galvanometer with a high resistance in series, in series with a dry cell. Its

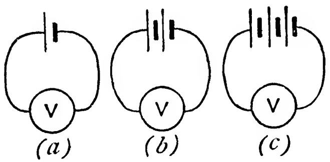

FIG. 61.—Cells in series.

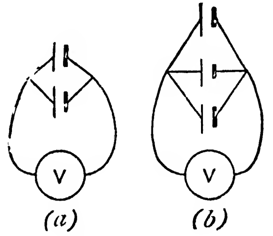

FIG. 62.—Cells in parallel.

position is shown at V in Fig. 61 (a). Read the volts or deflection. Replace the cell by another similar cell and read the e.m.f. in volts. Now place the two cells together and read the effective e.m.f. of the two in series as in Fig. 61 (b). Note that the e.m.f. together in series is the sum of the separate e.m.f.'s. Repeat, using a third cell and the three in series as at (c).

It should be noticed that with cells **in series**, the **combined e.m.f. is the sum of the separate e.m.f.'s.**

Repeat the above experiment, with the variation that the cells are in parallel instead of being in series. The arrangements are shown in Fig. 62 (a) and (b). If the separate cells have very nearly the same e.m.f., it should be noticed that with cells **in parallel the combined e.m.f. is only that of a single cell.** If the cells have different e.m.f's, the result is too complicated to be calculated here.

Expt. 23. **To calibrate a simple galvanometer.**—The process of **calibration** is that of finding the value in current corresponding to each deflection, so that the readings may be made to give the actual values of the current in amperes or milliamperes. The galvanometer *G* must be placed in series with a cell *E* and a resistance box *R*. For this experiment it is necessary to read both ends of the pointer and to take the deflections also with the current reversed. This reversal of the current may be performed by interchanging the connecting wires in the galvanometer terminals, or, more conveniently, by means of a key *ABCD* (Fig. 63). With plugs in *A* and *B* the current flows one way round the galvanometer, and the other way when the plugs are transferred to *C* and *D*. If the cell *E* is an accumulator, its e.m.f. is 2·1 volts, so that if the resistance in *R* is 2100 ohms, the current flowing is 2·1/2100 amperes; that is, 0·001 ampere, or 1 milliampere. With this arrangement, observe the four values of the deflection and take the mean, or average. Repeat with a resistance of 1050 ohms, in which case the current is 2 milliamperes; and so on, until the galvanometer readings become too great. Enter the results in the form of a table thus:

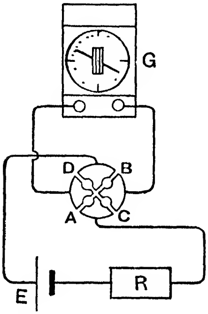

Fig. 63.—Calibration of galvanometer.

Resistance in ohms.	Current in milliamperes.	Deflections.				Mean deflection.
		Current direct.		Current reversed.		
2100	1					
1050	2					
700	3					
525	4					
420	5					
350	6					
300	7					
262	8					
233	9					
210	10					

Plot a curve of current and mean deflection. Such a curve is given in Fig. 64 and is called a **calibration curve.** It enables the current for any deflection to be found.

If an accumulator is not available, any other cell may be used, provided that its e.m.f. is known, so that the proper values of the resistance required to give 1, 2, 3, 4, etc., milliamperes can be calculated.

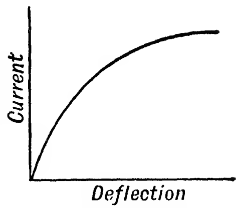

FIG. 64.—Calibration curve.

Potential difference.—The law connecting electromotive force, current and resistance for a whole circuit given on p. 57 is applicable to any part of a circuit, provided that there is no source of e.m.f. in this part. In this case the term electromotive force is not appropriate, but the corresponding quantity is called the **potential difference,** often written **p.d.**

Let the current be produced in a circuit as in Fig. 65. Consider part AB of the circuit, then for this part,

$$\frac{\textbf{p.d. between A and B}}{\textbf{current}} = \textbf{resistance of AB}, \quad \text{..........(7)}$$

or, $$\textbf{p.d. between A and B} = \textbf{current} \times \textbf{resistance of AB}. \quad \text{......(8)}$$

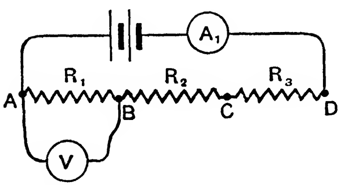

FIG. 65.—Measurement of p.d.

Potential difference, like electromotive force, is measured in volts, and the voltmeter is employed for its determination.

EXPT. 24. **Measurement of potential difference.**—Set up the circuit as in Fig 65, using known resistances for R_1, R_2 and R_3. These may be 10, 20 and 30 ohms. Connect a voltmeter to A and B as shown, and record the p.d. in volts. Now connect it to B and C, and again measure the volts; and again for C and D.

Now connect it to A and D and read the volts.
Show that

$$(\text{p.d. between } A \text{ and } C)+(\text{p.d. between } B \text{ and } C) \\ +(\text{p.d. between } C \text{ and } D)=\text{p.d. between } A \text{ and } D.$$

Further, show that

$$\frac{\text{p.d. between } A \text{ and } B}{R_1}=\frac{\text{p.d. between } B \text{ and } C}{R_2} \\ =\frac{\text{p.d. between } C \text{ and } D}{R_3}=\text{current}.$$

The current should be observed by means of the milliammeter A_1.

EXERCISES ON CHAPTER VI.

1. How does the current in a circuit depend upon the resistance of the circuit ? How would you show the general effect of increasing the resistance ?

2. What is the unit of resistance ? Describe the construction of some pattern of standard resistance.

3. Show by means of diagrams what is meant by "conductors in series" and "conductors in parallel."

4. A complete circuit consists of two conductors of resistances 23·5 ohms and 36·4 ohms. What is the resistance of the circuit ?

5. Sketch some form of resistance box, mentioning the materials of which the various parts are made.

6. What is a rheostat, and what is its use ? Sketch some form of rheostat.

7. Describe how you would measure the resistance of an incandescent lamp.

8. Give the relation between the electromotive force, current and resistance in a circuit. If the e.m.f. is 35 volts and the resistance 8·75 ohms what is the current ?

9. The terminals of a cell of e.m.f. 1·8 volt and resistance 1 ohm. are connected by two wires in series, of resistances 2·5 and 5·5 ohms. What is the current in the cell ?

10. If the two wires of Question 9 are placed in parallel instead of series, calculate the current in the cell.

11. Describe the principle on which a voltmeter is constructed. Sketch the electrical connections.

12. Give an account of a method of calibrating the scale of a simple galvanometer.

13. A cell of e.m.f. 2·1 volts, whose resistance is practically zero, maintains a current in two resistances of 2·3 and 4·7 ohms in series. Calculate the potential difference between the ends of the 2·3 ohm resistance.

14. A milliammeter reading 0 to 10 is required to be converted into an ammeter reading 0 to 10. How can this be done ?

15. A milliammeter of resistance 12 ohms, and reading 0 to 10, is required to be converted into a voltmeter reading 0 to 10 volts. How can this be done ? What resistance is required ?

CHAPTER VII

INCANDESCENT LAMPS

Early form of incandescent lamp.—When the possibility of producing electric current by machinery was realised, in the middle of the last century, the necessity for devising some form of apparatus by means of which a fine wire or filament could be raised to a sufficiently high temperature to emit light, became pressing. Such a filament must fulfil several conditions in order to obtain success. First, it must have such a high melting point that it can be rendered "white hot" without melting. Secondly, it must have a suitable surface for radiating light; and further, the material must not be too good a conductor, or the filament will have to be very long and fine, or else inconveniently large currents have to be employed to heat it.

The first attempt was made by using a platinum wire, sealed into a bulb. This metal has the advantage that it can be sealed into the glass of the bulb while the glass is soft, and as the two cool the platinum adheres to the glass, making a good joint, while the glass does not crack. Platinum is the only pure metal which behaves like this. The lamp made in this way is of no practical use, because the platinum melts at a temperature of about 1750° C. At this temperature the platinum emits light, but the efficiency is not great, for the proportion of the

energy given by the current, which is radiated as light, becomes greater the higher the temperature of the body. Platinum also has the advantage that it is not attacked by the air in the bulb, even at high temperature. But it should be noticed that it heats the air in the bulb, and a great deal of its energy is used in this way. This source of loss may be removed by exhausting the air from the bulb, but, even when this is done, the simple lamp of platinum is very inefficient.

Carbon filament lamps.—The production of the **carbon filament** first made possible the use of electric incandescent lamps for general lighting. Carbon is a very widely distributed element, and exists in many forms. Gas carbon is the remaining hard black substance when the gas has been distilled from coal. Soot is nearly pure carbon in a very friable form, and graphite or black lead and diamond are other forms of nearly pure carbon. Carbon is an essential constituent of all living matter, and on heating any animal or vegetable substance to drive off the volatile parts, carbon remains. The heating must be carried out without the presence of air, or the carbon will burn; that is, it will combine with the oxygen of the air to form the gas carbon dioxide.

In all its compact forms carbon is a fairly good conductor of electricity, it is so common that its cost is practically nothing, and it does not melt at any temperature attainable. It is therefore a very suitable substance for the filaments of lamps, but it combines so readily with the oxygen of the air at high temperatures that air must be excluded from the bulb of the incandescent lamp.

Manufacture of carbon filaments.—Various methods are employed for the manufacture of carbon filaments, although the same principle is common to them all. The carbon contained in cotton is the commonest source of

supply. Cotton wool is treated with a solution of zinc chloride, which breaks up the fibres, forming a paste. To get the substance in the form of a filament, the paste is pressed through holes of the required size in a metal plate. They emerge from the plate into alcohol where they are left for several hours to harden. At the end of this time they are still sufficiently pliable to be bent into the shape required for the lamp. They are therefore washed and then bent on block carbon "formers" into their final shape. It still remains to get rid of the materials in the cotton wool other than the carbon. This is done by heating to a temperature of about 2000° C. out of contact with air, the filaments being still on their "former" and being packed round with powdered carbon. At this temperature all other constituents of the cotton wool pass off as gases, and the hard carbon filament remains.

Since carbon cannot be sealed into the glass walls of the bulb, the ends of the filament are attached to platinum wires. On placing in some liquid containing carbon, such as petroleum or benzine, and heating the joint by passing a current through it, carbon is deposited on the joint, so making a good strong contact.

The filament so produced and mounted is still in an unsatisfactory form, being brittle, wanting in uniformity of section and of dull rough surface. These faults are remedied by the process of **flashing.** A current sufficiently strong to raise the filament to incandescence is passed through it while it is situated in some hydrocarbon vapour, such as benzine. The vapour is decomposed at this high temperature, and the carbon is deposited upon the filament. Since the thinner parts of the filament become the hotter, carbon is more rapidly deposited there, so that after a short time the filament is rendered

very nearly uniform in thickness. Further, the resistance of the filament drops as the deposition of carbon takes place, so that if the filament has a higher resistance at the start than is required for the finished lamp, the flashing may be continued until the desired resistance is attained.

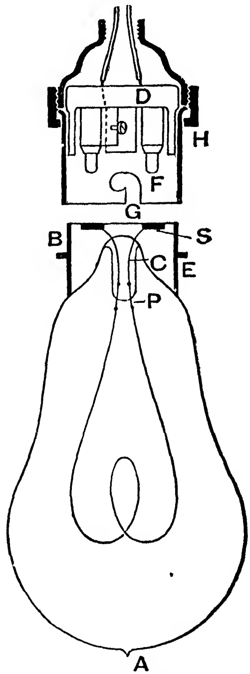

FIG. 66.—Carbon filament lamp with lamp-holder.

Sealing and exhausting.—The filament is next sealed into the bulb, which is blown on a tube at A (Fig. 66). The platinum wires P which pass through the glass are sealed on to copper wires C, and make contact with the studs S, the whole being cemented into the brass cap B by some form of insulating cement which does not absorb moisture. On exhausting the air by means of mercury air-pumps the bulb is sealed off at A and is ready for use.

Lamp holders.—On the first production of incandescent lamps, screw holders were employed. That is, the glass globe was provided with a brass cap whose outer surface was a screw thread, and this cap screwed into the brass lamp holder. One end of the filament was attached to the screw surface and the other to a central contact stud which made contact with a similar stud carried by and insulated from the holder.

For almost all purposes the bayonet-clip form of holder has replaced the screw pattern. The studs S (Fig. 66)

press against the contacts *F*, which are held in contact with *S* by interior springs not shown. The studs *F* are embedded in a porcelain insulator *D* and the leads that bring the current to the lamp pass through *D*, and the bared ends are held into the studs *F* by means of set screws. The lamp is placed in the holder by placing the projections *E* into the corresponding slots *G*, pressing it home and giving it a slight turn. The lamp is thus easily placed in position and contact is made automatically.

Metal filament lamps.—Although platinum was found to be an unsuitable material for lamp filaments, other rare metals have been employed successfully in recent years for that purpose, in fact their use has revolutionised the manufacture of incandescent lamps. **Tantalum,** one of the heavy metals, has a very high melting point, about 2000° C., and has the convenient property of being ductile, and can thus be drawn into very fine wires in a similar manner to copper and other ductile metals. It can be drawn into wire having a diameter of only 0.05 mm., which is about the size required for incandescent lamps. A considerable length of wire is generally necessary, and this wire is looped backwards and forwards on supports, somewhat as shown in Fig. 67, and is sealed into the bulb, which is exhausted as in the case of the carbon lamp.

The metal **tungsten** is, like tantalum, very suitable for use as the filament of incandescent lamps, but, unlike tantalum, it is very brittle. For some time tungsten filaments were made by forming a paste of finely divided tungsten with some gummy material, and pressing the paste through fine holes, as in the case of carbon filaments (p. 66). They were then heated by an electric current, out of contact with air, until nothing but pure tungsten

remained. The early " Osram " lamps were made in this way. Their only drawback was the brittleness of the filament.

More recently it has been found that by hammering when hot, a mass of tungsten may be welded into a compact mass, which is ductile when cold. The tungsten

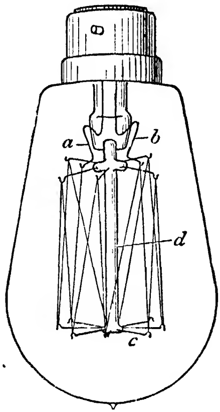

FIG. 67.—Metal filament lamp.

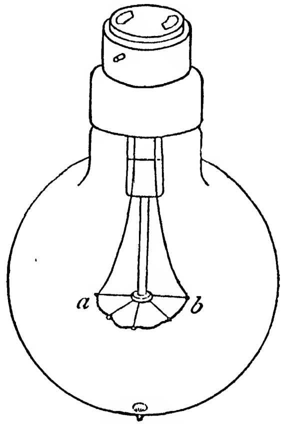

FIG. 68.—Half-watt lamp.

wire is attached to stout wires at *a* and *b* (Fig. 67) and passes up and down the lamp, forming a zig-zag pattern. At the lower ends of the lamp the tungsten wires pass over very fine flexible wires *c*, held by a glass stem *d*. These flexible wires keep the tungsten filament tight even when expanded through heating. The strength of the lamp is thus almost equal to that of a carbon filament lamp.

Half-watt lamps.—A still further improvement in lamps has been made recently by redesigning the lamp itself. One of the limits set to the efficiency of incandescent lamps is due to the **blackening of the bulb.** This

is caused by particles of the carbon or the metal being given off from the filament and collecting on the inner surface of the bulb. This takes place more rapidly the higher the temperature of the filament, and since it results in a cutting down of the light emitted by the lamp, it prevents the use of sufficiently high temperatures for the radiation of light to reach its greatest effectiveness.

In the half-watt lamp, the fine tungsten filament is in the form of a minute spiral reaching from *a* to *b* (Fig. 68), supported by fine wires at several points. The bulb, instead of being empty, contains the gas nitrogen, which is so inert that it does not attack the filament even at high temperature. The gas near the filament becomes heated and rises, just as hot air will do, and carries the particles of tungsten liberated at the high temperature up into the top parts of the bulb, where they are deposited, but do not interfere with the light leaving the bulb through the sides and bottom. The nitrogen which fills the bulb is at about half the ordinary atmospheric pressure.

Rate of working ; watts.—In order to understand how the efficiency of a lamp is measured, it is necessary to turn again to the definition of the ampere (p. 35) and the volt (p. 56). The rate at which work is being done in any circuit, or in any conductor, depends upon the current flowing and the electromotive force driving it. This power or rate of working is the product of current and e.m.f. for the whole circuit, or, in the case of a single conductor, it is the product of the current and potential difference for that conductor.

Thus : **rate of working = current × e.m.f.**

or for a given conductor :

rate of working = current × p.d.

The unit of rate of working, or power, is derived from the ampere and volt and is called the **watt**, after James Watt, the celebrated engineer.

Therefore for any circuit,—

$$\textbf{Power in watts} = \textbf{amperes} \times \textbf{volts.} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Thus, if a lamp takes 0·5 amperes on a 100 volt circuit

$$\begin{aligned} \text{Power} &= 0{\cdot}5 \times 100 \\ &= 50 \text{ watts.} \end{aligned}$$

Such a lamp would be called a 50-watt lamp.

Since the mechanical engineer measures power or rate of working in horse-power, it may be useful to note that,—

1 horse-power = 746 watts.

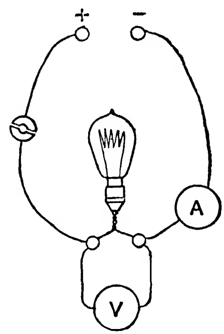

Fig. 69.—Measurement of power.

Expt. 24. **To measure the power absorbed by a lamp.**—Connect the lamp up to the supply mains with a suitable ammeter and voltmeter as shown in Fig. 69. The **ammeter** must be **in series** with the lamp, and the **voltmeter in parallel** with it. Read the current and p.d. Replace the lamp by another and repeat. Perform the experiment for several lamps and tabulate the results as follows, calculating the power from equation (1).

Name of lamp.	Volts.	Amperes.	Watts.

Candle-power.—The question of illumination is outside the scope of this book, but a few elementary considerations

may be given. As a standard of illuminating power, the candle is unsuitable because it is not constant, but the unit of illuminating power was originally derived from the candle of a standard form, that is, a candle made of spermaceti, weighing one-sixth of a pound and burning 120 grains in one hour. The present standards consist of lamp flames, or incandescent lamps, used under specified conditions, but the unit taken is still the **candle-power.**

The light received must travel horizontally from the candle, and the same rule generally applies to the illumi-

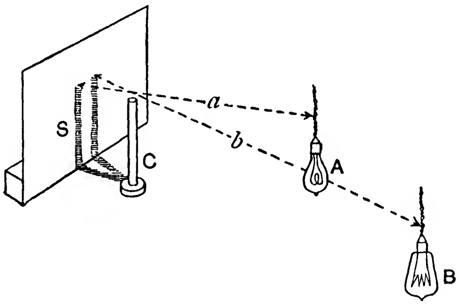

FIG. 70.—Photometer.

nating powers of incandescent lamps. When the illuminating power for different horizontal directions is not the same, an average of a number of measurements in different directions is taken and is called the **mean horizontal candle-power.**

Photometers.—Any apparatus for measuring the illuminating power of a source of light is called a **photometer.** There are many forms of photometer, but most of them depend upon the principle that if the two sources of light are adjusted to such distances from a screen that they both illuminate the screen to the same intensity

then **the illuminating powers of the two sources are proportional to the squares of their distances from the screen.**

One simple and effective arrangement is shown in Fig. 70. The lamps A and B are adjusted in position until the shadows of the rod C cast by them on the screen at S are side by side and of equal darkness. The eye can judge this fairly well if one of the lamps is kept moving nearer to and further from the screen, through gradually diminishing distances. The distances a and b of A and B from the screen are then measured.

Then, $$\frac{\text{candle power of } B}{\text{candle-power of } A}=\frac{b^2}{a^2}. \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

If the candle-power of A is known, that of B can be calculated.

EXAMPLE.—Let the candle-power of the lamp A be 8, and the distances a and b are 18 and 54 when the shadows are equally intense. What is the candle-power of B?

$$\frac{\text{Candle-power of } B}{8}=\frac{54^2}{18^2}=\frac{3^2}{1^2}=9$$

$$\therefore \text{ Candle-power of } B=8\times 9$$
$$=72.$$

EXPT. 26. **To compare the candle-powers of two lamps.**—Arrange the two lamps, a rod and screen, as in Fig. 70. Adjust the distances of the lamps from the screen until the two shadows are equally dark, and measure the distances from the screen. Repeat with different distances, taking six different positions, and tabulate the results as follows.

A's distance	B's distance	$\frac{b^2}{a^2}$
	Average	

Taking an approximate known value for *A*'s candle-power, calculate the candle-power of *B* from equation (2) above.

If one of the lamps be replaced by an ordinary paraffin candle an approximate value of the candle-power of the remaining lamp may be found. But it should be remembered that the result will generally be too high, because the ordinary candle has usually less than the standard candle-power. Nevertheless the experiment may be performed for practice.

Efficiency of incandescent lamps.—The most reasonable method of considering the efficiency of a lamp would be to take the illuminating power for each watt absorbed by the lamp, since the greater the efficiency, the more will be the light emitted for a given rate of expenditure of energy upon the lamp. In spite of this, the reverse meaning has, by custom, been given to the term. Thus the efficiency of a lamp is given as **the number of watts per candle power.** Thus the greater the energy required to produce each candle-power the greater is the nominal efficiency of the lamp although it is less efficient as a producer of light.

EXPT. 27. **To measure the watts per candle-power of a lamp.**—Some standard of illuminating power must be obtained, and the candle-power of the given lamp measured as in Expt. 26. In setting up the lamp, an ammeter must be included in the circuit, and a voltmeter placed across its terminals, as in Expt. 25. The watts and candle-power being then found, the number of watts per candle-power can be obtained.

Efficiency and life of various lamps.—Any form of incandescent lamp should last for 1000 hours actual running. It does not follow that it is economical to run the lamp until the filament breaks, for the watts per candle-power will generally rise as the lamp is used. The most important cause of this change is the blackening of the bulb, due to particles from the filament being deposited upon

the inner surface of the glass. Another cause is the disintegration of the filament, the surface of which becomes rough, while the mechanical strength gets less. The curves in Fig. 71 are typical of the behaviour of the different kinds of lamp. The carbon lamp starts with an efficiency of 3 to 4 watts per candle-power, and after a slight temporary change, the candle-power falls throughout its life, with consequent rise in the watts per candle-power. In the case of the metal filament lamp, the candle-power and efficiency remain much more nearly constant throughout the life of the lamp than in the case of the carbon filament lamp.

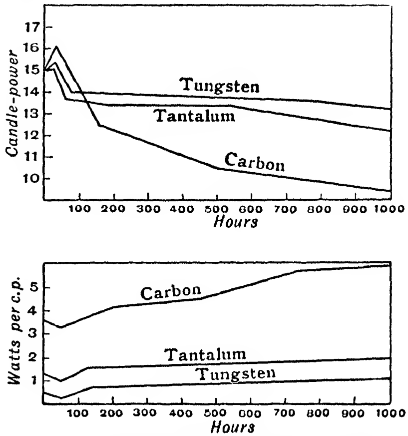

FIG. 71.—Efficiency curves for incandescent lamps.

Illumination with varying voltage.—It is a well-known fact that carbon filament lamps are much more sensitive to changes in the voltage of the supply than are metal filament lamps. A small rise in voltage causes a large increase in the candle-power of the carbon filament lamp, while a drop causes a correspondingly large fall in illuminating power. The reason for this is that the resistance of a carbon filament decreases as the temperature rises, the resistance of the filament when the lamp is emitting light being about half the value for the filament when cold. Hence a rise in voltage, which, of course, increases the current and raises the temperature, causes a drop in the resistance, which produces a further rise in current. All

metals increase in resistance when the temperature rises, so that if, in using a metal filament lamp, the voltage of the supply increases, the increased current raises the temperature and the resistance increases. This has a regulating effect which steadies the illuminating power of the metal filament lamp, and is in contrast with the unsteadiness of the carbon filament lamp.

EXPT. 28. **Resistance of incandescent lamp, hot and cold.**—Measure the resistances of two lamps, one having a metal filament and the other a carbon filament, by the method of Expt. 19. Now measure the resistances of the same lamps when running, by means of the arrangement in Expt. 25. Instead of multiplying the current and p.d. to obtain the watts, divide the p.d. by the current to obtain the resistance. Note that the resistance of the carbon filament is very much less when hot than when cold, but the resistance of the metal filament is greater when hot than when cold.

EXERCISES ON CHAPTER VII.

1. Give a short account of some of the difficulties met with in the early production of incandescent lamps.

2. Describe the manufacture of a carbon filament lamp.

3. What are the advantages of the metal filament lamp over the carbon filament lamp ?

4. Describe a " half-watt " lamp.

5. What is the unit of rate of working used in electrical measurements ? What is the horse-power required to maintain alight 15 lamps, each of which takes 40 watts ?

6. Describe how you would measure the candle-power of an incandescent lamp.

7. If 200 incandescent lamps each requiring a p.d. of 105 volts and having a resistance of 75 ohms, are maintained alight, find the total current and the total power in watts required.

8. What is meant by the efficiency of an incandescent lamp? How may the efficiency be measured?

9. Give an account of the relative efficiencies of carbon filament and metal filament lamps throughout their lives.

10. Explain why it is that fluctuations in the voltage of supply cause greater variations in brightness in the case of a carbon filament than in that of a metal filament.

CHAPTER VIII

LIGHTING AND HEATING

Switches.—The very wide distribution of electric current for lighting, heating and power has made the necessity for producing certain appliances in some standard efficient form. Among these appliances may be noticed **switches,** which are used for interrupting the current or completing the circuit at will, and **fuses** for breaking the circuit when the current rises to the limit of safety. An efficient switch must satisfy two conditions—it must be well insulated, so that the person who operates it does not become electrically connected with the circuit carrying the current, and it must break the current so rapidly that any spark formed is rapidly quenched. For purposes of lighting by incandescent lamps, where the supply is at from 100 to 240 volts, and currents not exceeding 10 amperes are carried, a simple form of switch known as the **tumbler switch** is generally employed. One form of the tumbler switch is shown in Fig. 72. The current enters by means of the cable at A, which is screwed into a brass socket, thence by a bent copper strip B to one arm of a brass lever CED which is pivoted at E and out by a similar brass socket F. The lever CD can be raised from contact with B and K by moving the brass knob G from the position shown in (b) to that shown in (a). The porcelain link H carries out this motion. On moving the knob

G, to raise the contact arms C and D, the steel spring S helps the motion and throws C and D up quickly, so that the spark produced on interrupting the current is quenched rapidly. The insulating porcelain base of the switch is

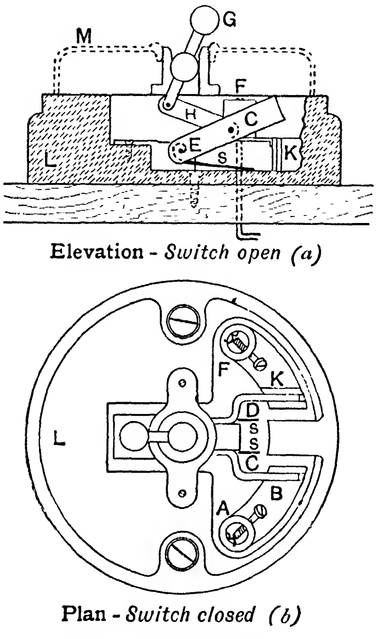

FIG. 72.—Tumbler switch.

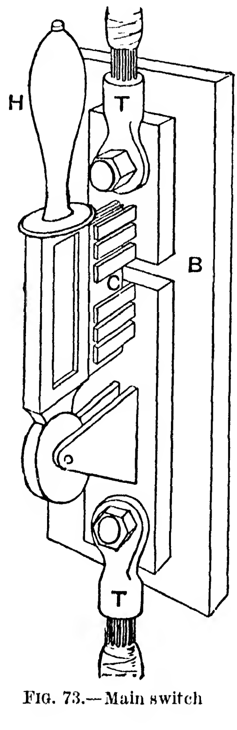

FIG. 73.—Main switch

glazed, and the brass cover, which can be screwed on or off, is shown in dotted line at M.

For greater currents a more massive switch is necessary, of which there are many designs. One form of main switch is given in Fig. 73. The insulating handle H is attached to the massive metal piece which carries the contact bar C which connects the brass terminal blocks,

to which are bolted gun-metal thimbles *T* into which the ends of the cable are soldered. The switch is carried by an enamelled slate base *B*.

Wires and cables.—In the public supply of electric current, safety from leakage and overheating are the first considerations, therefore the **insulation** of the wires and cables, and their **size**, are of the greatest importance. The insulation usually consists of india-rubber, either pure or vulcanised, the latter being harder than pure rubber. Rubber is vulcanised by heating in contact with sulphur by means of steam at a temperature of 125° C., but the steam is not allowed to come into contact with the rubber. A single electric light wire is shown in Fig. 74. This consists of a single drawn copper wire *W* covered with a layer of rubber, this being protected by a layer of braided cotton, which is rendered damp-resisting by passing through hot paraffin wax, or some similar material. The wire itself is made of fairly pure copper and is coated with a layer of tin, both to preserve the copper from oxidation when in contact with the air and to render the process of soldering easy when making joints.

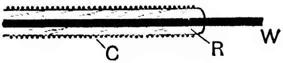

FIG. 74.—Electric light wire.

The sizes of wires are given according to the Legal Standard Wire Gauge. A few of the more commonly occurring are given in the table on the next page, with their diameters in millimeters and the current permissible in electric lighting systems.

It should be noted that single wires are seldom used on permanent lighting systems, a stranded cable being employed. Thus, instead of a single No. 18 wire, a cable consisting of three strands of No. 22 would be used. This is much more flexible, and less likely to break at

a sharp bend. A seven strand cable is shown in Fig. 75 with its coating of pure rubber, rubber tape, vulcanised rubber, canvas tape and outer lair of paraffined braiding.

TABLE OF WIRES.

S.W.G.	Diameter.	Current permissible.	S.W.G.	Diameter.	
19	2·03 mm.	19 amp.	24	0·559 mm.	Not used for lighting.
16	1·62 ,,	12·9 ,,	30	0·315 ,,	
18	1·21 ,,	7·2 ,,	36	0·193 ,,	
22	0·711 ,,	(3 strands 7·2 amp.)	40	0·122 ,,	

Fuses.—Many devices have been used for the protection of electrical systems against the evil effects of too great a current. There are many accidental circumstances that may cause a rise in current, amongst which may be noticed **short-circuiting,** or the touching of bare conductors so that the current takes a short path instead of going through the lamps, etc.; and the deterioration with time or damp, of the insulation of the system, so that current leaks from the cables **to earth.** In either case the overheating may give rise to a fire, and if the wires are laid in **wooden casing** this is much more likely to be the case than if they are laid in iron or steel tubes. On the other hand, the latter are much more likely to cause **earths** or **shorts** if the wire is carelessly put in, as the insulation may be cut very easily in the process of drawing in.

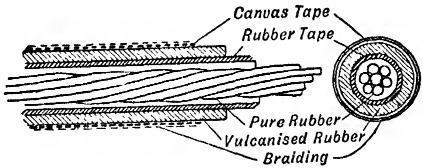

FIG. 75.—Stranded cab

For protection against these accidents some form of **cut-out** must be employed, and for currents such as are used in houses or public buildings some form of **fuse** is universally used. Where many fuses are used in the same system of supply, they should be placed all together in some easily accessible place, so that they may be inspected frequently. In the form of fuse shown in Fig. 76 the fuse wire *F* is joined to the terminals *B* and *C* attached to brass clips screwed to the porcelain block *A*. The wire may be of lead, tin or tinned copper and must be of such size that when the current in it reaches the limiting value for safety, the heat produced melts or fuses the wire, and the circuit is broken. The fuse may be renewed by removing the block *A*, by drawing from the clips *D* and *E*, putting in a new wire and replacing the block.

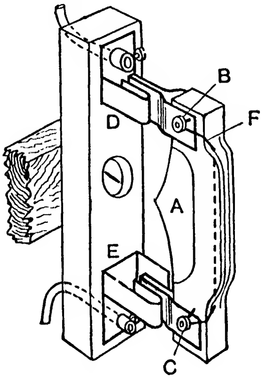

FIG. 76.—Fuse.

The following table gives approximately the fusing current for copper and for tin wires; but it must be remembered that these vary according to the length of the fuse and its situation, that is, whether it is enclosed or in the open air.

FUSING CURRENT FOR BARE WIRES.

S.W.G.	Tin.	Copper.
No. 22	8 amp.	50 amp.
26	4 ,,	25 ,,
30	2 ,,	15 ,,
36	1 ,,	6 ,,
40	—	3½ ,,

House wiring.—Incandescent lamps are always used in parallel. There are several reasons for this. For steadiness of illumination there must be a constant potential difference between the terminals, and the p.d. for each lamp is only that between the supply mains, whereas if the lamps were in series a much higher p.d.

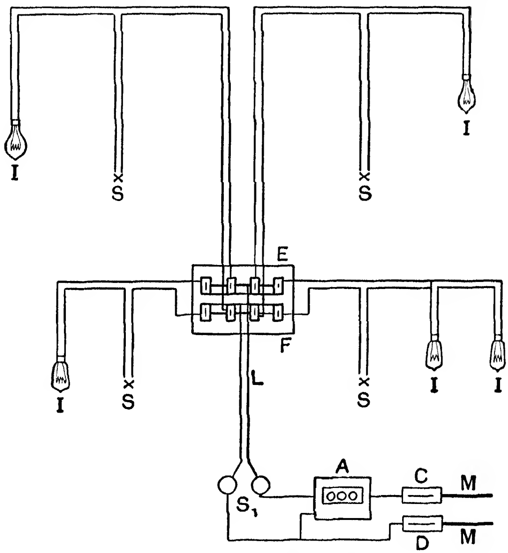

FIG. 77.—House wiring system.

between the mains would be required. An additional advantage of the parallel system is that if the filament breaks one lamp alone is affected, but if there were several lamps in series, the breaking of one would put the whole series out.

To carry this plan into effect, there are many ways of wiring a building, but only one will be given. The supply mains *MM* (Fig. 77) are of fairly heavy cable and lead to the electric meter *A* through a pair of fuses

C and D. There is a double pole switch S_1 between the supply and the wiring system. From here, a pair of leads L, sufficiently stout to carry the current for the whole building, goes to the **distribution board** EF, where they are connected each to a brass or copper bar called a **bus bar**. The leads for separate rooms, or separate lamps, are connected to the bus bars by fuses of the type shown in Fig. 76, one wire of each pair going to the switch S and the other to the lamp I, the circuit being completed as shown. It will be noticed that the leads, being of copper wire, are of low resistance; but if the leads are long, they may be of appreciable resistance, and there is some p.d. between their ends when the current flows. It follows that there is not the whole p.d. of the supply between the terminals of any one lamp. Consequently the leads must be made sufficiently thick to reduce the potential drop along them to a small amount. Hence, for this reason the leads must be thicker when the distance of the lamp from the mains is great than when it is small.

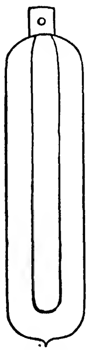

FIG. 78.—Radiator lamp.

Electric Heaters.—For the heating of rooms, electricity is very expensive, but it has the advantage that when a **radiator** is employed, the heat may be produced at any part of the room where it is required, and only for the time required. It can be switched off directly it is done with. As **radiators**, high power carbon incandescent lamps (Fig. 78) are commonly used. These are usually long and have a frosted-glass surface. They are arranged in sets of two, three, or four, in a metal stand, and are backed by polished metal reflectors. These radiators are generally made up of 250-watt lamps.

When the whole room is to be heated, metallic resistances are employed. The temperature in this case is not nearly so high as with radiators. Air comes into contact with the hot wire, or with a cement in which it is embedded, becomes heated, expands and rises, giving rise to currents, which, in time, warm the whole room. Continuous heating by this means is much more expensive than heating by coal or gas, but has the advantage that no objectionable fumes are produced.

Electric kettle and iron.—Electricity may be employed fairly economically for heating when it is required to heat only a small body, as in boiling water in a kettle or heating an iron, because nearly all the heat produced by the current is used in heating the body. In both the cases mentioned, the current passes through a resistance wire such as manganin or eureka, embedded in some suitable cement or enamel. In Fig. 79 the heating wire W is shown embedded in the cement or enamel C, the lower part of the figure being drawn in section. As the rise in temperature which would be produced if no water had been put into the kettle, would be injurious, a little fusible metal plug P is placed in the circuit of the heating wire. Any overheating will then fuse the plug and break the circuit. Ovens and cooking sets are now made on a similar principle to the above. The resistance of the heating wire will, of course, be less on a 100 volt supply than on a 200 or 240 volt supply.

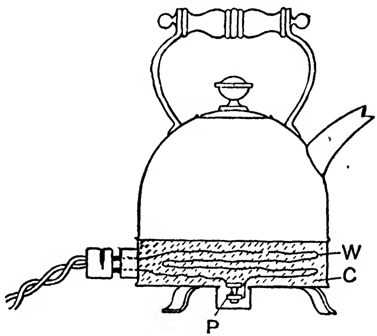

FIG. 79.—Electric kettle.

EXERCISES ON CHAPTER VIII.

1. What are the necessary qualifications of a good switch? Give a sketch of some form of switch.

2. What is the object of a fuse? What kind and size of wire would you use for a 4 ampere fuse?

3. Give a drawing of a section of a seven-strand cable.

4. Make a diagram of some suitable arrangement for wiring a seven-room house for electric light.

5. Give the relative advantages of gas and electric heating for a room.

6. Describe some form of electric kettle or electric iron.

7. Give the relative advantages of electricity and coal or gas for heating.

CHAPTER IX

THE ELECTRIC ARC

Distinction between a spark and an arc.—It will have been noticed already by the student that whenever an electric circuit is broken, a **spark** occurs at the point of break (p. 10). In most cases, particularly when the current is produced by cells, the spark is very small, and lasts for a very short time. In fact it is often difficult to detect the spark in daylight. But with large currents, especially when the circuit contains turns of wire surrounding iron, as in the case of an electro-magnet, the spark may be large and becomes a source of trouble (p. 10). With small voltages the spark, even when large enough to call a flash, soon disappears, but with high voltages the flash may persist, and is then called an **arc**. In both the spark and the arc, the temperature is so high that the metals between which it is formed are melted and even vaporised, the vapour forming a conducting bridge across the gap. When the arc is formed, the current produces sufficient heat to maintain this conducting bridge.

Arc between carbons.—The metals are good conductors of heat, so that the metal of the edge of the gap is rapidly cooled. Further, the metals, having comparatively low melting points, are melted at the edges of the gap and the conductors are quickly used up. For these reasons it is difficult to maintain an arc between metals. The

substance carbon, however, is very suitable for producing the arc. If a source of current at over 40 volts be applied to the terminals CD (Fig. 80), which are situated on metallic arms carrying the two carbon rods A and B, no current flows until the carbons are moved by means of the rack and pinion movement EF, until they touch each other, when a considerable current is established. On separating the carbons, the tips become white hot and between the tips is seen a bright flame-like arc, usually violet in colour. This arc persists unless the carbons are too far separated for the current to pass.

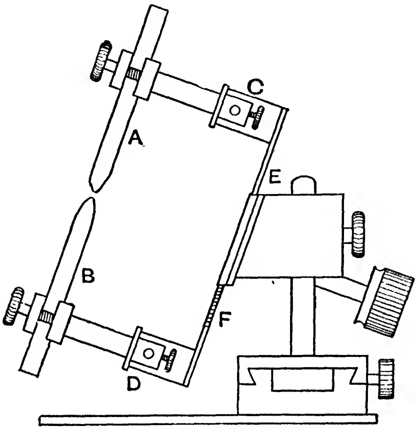

FIG. 80.—Hand-feed arc lamp.

In order to examine the arc, care must be taken to protect the eyes, by viewing it through smoked or ruby glass, because the intense light not only produces a painful impression but is very injurious to the eyes. Another useful method of observing the arc is to throw an image of it upon a white screen or piece of paper by means of a simple lens, as shown in Fig. 81. AB are the actual carbons and the current is supposed to enter at A

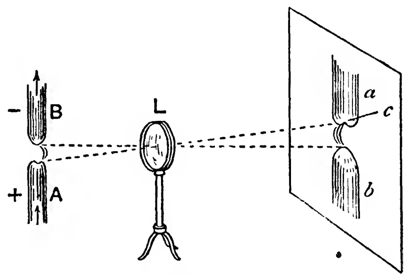

FIG. 81.—Inspection of the arc.

and leave at B. A is then called the positive and B the negative carbon. The image produced by the lens L is seen at ab, and the illumination on the screen is not sufficiently great to be harmful to the eyes. This arrangement avoids the necessity for smoked glasses and has the further advantage of magnifying the arc.

The first glance shows that both carbons are hot, but there is one spot on the positive carbon a at which the temperature is far higher than at the rest of either carbon. This spot is called the **crater**, because the carbon burns away much more rapidly here than elsewhere, so that the surface very soon becomes cup shaped, like the crater of a volcano. Owing to combustion of both carbons in air, the ends soon acquire a rounded, somewhat conical, form. Owing to the fact that the positive carbon is at a higher temperature than the negative, it burns away more rapidly. For this reason positive carbons are sometimes made to have about twice the area of cross section of the negative carbons.

The carbons are usually made by mixing the carbon left on distilling coal tar, powdered graphite, and a syrup of sugar or gum, to form a paste. This is then forced through a circular die, to form it into circular rods, and these rods are baked at a bright red heat, out of contact with air, so that most of the volatile substances are driven off. When uniform carbons are used, the crater does not keep a fixed position, but wanders over the surface of the carbon. Since the greater part of the light is emitted by the crater, which has a small area, it follows that the negative carbon will cast a shadow by obstructing the light. Hence, for use in lanterns, where the light is required in a horizontal beam, the carbons are tilted as shown in Fig. 80. Any wandering about of the crater would give rise to very objectionable fluctuations in

illumination. This difficulty is got over by making the positive carbons with a soft core. This core readily volatilises, and hence the arc always springs from the edge of the core, which, being small, confines the wandering of the crater to a very small amount.

Current and p.d. required for the arc.—The arc cannot be maintained with a very small current. For continuous working 8 amperes is the smallest current usually employed. As the current is increased, the temperature of the hottest part of the crater, which is from 3500° C. to 4000° C. does not rise, but the crater itself increases in area, so that a wider path is offered to the current. The true resistance of the arc is small, about half an ohm, but there is a definite and nearly constant e.m.f. of nearly 40 volts required to maintain any arc at all. To maintain a steady arc an e.m.f. higher than 40 volts is necessary, for, if only 40 volts were used, any accidental change in the circuit would bring the p.d. between the carbons so near to its critical value that great variations in current and illumination would occur, and the arc might easily be quenched. It is necessary, therefore, to use a resistance in series with the arc. In order to calculate the value of the resistance to be used in series with an arc requiring 12 amperes, running on a 100 volt circuit, notice that the p.d. between the carbons is 40 volts.

$$\therefore \text{ Resistance of remainder of circuit} = \frac{100 - 40}{12}$$

$$= 5 \text{ ohms.}$$

Hence a resistance, generally in the form of coils of bare platinoid wire stretched on a frame, having a resistance of 5 ohms, must be included in the circuit.

This series resistance is used for another reason. When,

for any reason, the current in the arc increases, it was seen above that the crater becomes larger, and consequently the resistance of the arc itself decreases. It follows that with constant p.d. applied to the arc, a further increase of current would occur. Hence the arc alone would be unstable ; for any increase in current would cause a further increase, and so on indefinitely. On the other hand, a decrease would cause a diminution of the crater, with consequent increase of resistance of the arc, which would produce a further drop in current. The arc in this case would eventually become quenched.

This instability of the arc is prevented by using a sufficiently great resistance in series with it, so that the fluctuations in resistance of the arc itself are only a small fraction of the whole resistance of the circuit.

Hand feed arc lamps.—When using an arc for a projection lantern, the hand-feed pattern shown in Fig. 80 is very efficient. For **striking the arc**, the carbons are moved into contact, when the current starts. The local heating at the points of contact, owing to the resistance, causes the carbons then to become hot. In the act of separating the carbons this heating increases, and when actually separated, the phenomena of the arc, as described above, are produced. If the carbons are too far apart there is a great drop in luminosity and the crater wanders about, producing flickering. When the carbons are too close, a violent hissing noise is produced and the negative carbon is liable to hide the crater. The correct distance apart is easily found in practice, and is about 3 mm. As the carbons burn away, this may be corrected by moving the carbons together, which operation may be performed every few minutes.

EXPT. 29.—**Action of solenoid upon soft iron.**—Obtain a piece of brass tubing of 1 to 1·5 cm. diameter, 10 cm. long,

and wind upon it four layers of No. 18 cotton-covered copper wire. Connect the coil in series with an ammeter A, rheostat R and battery of a few cells E, as in Fig. 82. Hang up a piece of soft iron bar 10 cm. long which slips easily through the tube, suspending it by a spring balance B. Maintain a steady current of 2 amperes throughout the experiment, adjusting it by means of the rheostat if necessary. Read the weight of the rod, as indicated by the spring balance, when no current is flowing. Starting with the bottom of the coil level with the top of the rod, and with the current on, take the reading of the balance. Deduct this from the first reading, thus obtaining the upward pull of the solenoid upon the rod. Repeat, with the bottom of the solenoid 2 cm. below the top of the rod, and continue in this way, moving the coil down the rod 2 cm. at a time, and record the results thus:

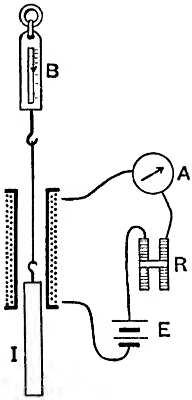

FIG. 82.—Effect of a solenoid.

Distance of bottom of solenoid from top of rod.	Apparent weight.	Pull due to solenoid.
0 cm.	...	...upwards
2 ,,		
4 ,,		
6 ,,		
8 ,,		
10 ,,		
12 ,,	...	... downwards
14 ,,		
16 ,,		
18 ,,		
20 ,,		

Make a graph of the numbers in the first and last columns. It will be seen that the coil always draws the rod towards its middle part.

Automatic arc lamp.—From the action of a solenoid upon a soft iron rod, the **automatic arc lamp** has been devised. To understand how this has been done, consider the upper carbon to be carried at B (Fig. 83) by a soft iron rod G which lies partly inside a solenoid, through which the current feeding the arc flows. The path of the current is $ABCDEF$. Before the current flows, the carbons touch at C on account of the weight of the iron rod and the upper carbon. On switching on the current, the iron core is raised by the upward pull due to the solenoid, as described in Expt. 29. This process **strikes the arc.** If the upper carbon is pulled up too far, the current drops, owing to the increased resistance of the arc, and the carbon falls. The regulation of the length of the arc is therefore automatic, and this length is determined by the weight of the moving parts and the arrangement of the solenoid.

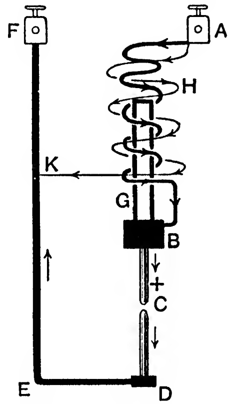

FIG. 83.—Principle of the automatic arc lamp.

This regulation is rendered more delicate by a second or **shunt coil** H connected in parallel with the arc and wound in such a way that the current in it weakens the effect of the first or **series coil**. Thus, when the arc becomes too long, not only does the effect of the series coil in the solenoid become less, but the current in the shunt coil becomes greater, and so further weakens the pull of the series coil.

This simple arrangement is not very good mechanically ; also the running of the lamp is accompanied by considerable flickering owing to the unsteady motion of the upper carbon. There are many mechanical forms of automatic

feed, controlled by series and shunt solenoids, as described above. One of these forms is illustrated in Fig. 84. The lower or negative carbon is fixed, and the upper or positive carbon is carried by a rod *R* provided with a rack into which the pinion *P* gears. The pinion is part of a larger wheel *W* which is driven forwards by a ratchet and pawl shown at *L*. The current flowing in the carbons passes also through the series coil *Se* and draws upwards the iron plunger, raising the right hand end of the lever *BC* and so turning the wheel *W* by means of the ratchet and pawl *L*. This action strikes the arc. As the carbons burn away, or if the arc for any reason becomes too long, the current in *Se* falls and that in the shunt coil *Sh* rises, both of which effects cause the lever *CD* which is pivoted at *D* to tilt, so that the end *B* is lowered. The lever which carries the pawl is therefore lowered, and a fixed pin *A* trips up the pawl *L*, and the weight of the positive carbon and carrier *D* feeds the carbon forward, since the wheel *W* is now free to turn. If the arc becomes too short, the carbon is raised exactly as in the action of striking the arc.

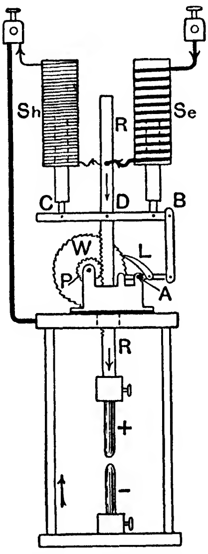

FIG. 84.—Automatic arc lamp.

Enclosed arc.—With the ordinary **open arc**, the atmosphere has free access to the carbons, which, at the high temperature of the arc, burn away fairly rapidly. In order to render this process much slower, the arc is sometimes enclosed in a glass bulb or globe, which is very nearly air-tight. As the carbons burn away, the gases

produced (chiefly carbon dioxide) fill the globe. The rapid burning away of the carbons is therefore prevented. With this **enclosed arc**, the length of the arc is greater than with the open arc, being sometimes 10 to 12 mm. Also, higher voltages are required, these being of the order of 80 volts. Since the carbons are far apart there is less obstruction of the light by the negative carbon (p. 89). For these reasons the enclosed arc is more economical than the open arc.

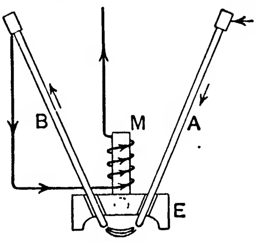

FIG. 85.—Flame arc.

The flame arc.—In recent years a form of arc of very high efficiency, called the **flame arc**, has come into use. The carbons AB (Fig. 85) are longer and thinner than those of the ordinary arc, and are impregnated with certain metallic salts. Calcium salts, such as lime, give a golden yellow light, barium salts white, and strontium crimson. Also, the volatilised salts produce an arc of considerable conductivity, which may therefore be of considerable length and possesses high luminosity. The carbons are inclined to each other as in the figure, and their tips project through a white porcelain inverted cup E, which protects the arc from draughts and also acts as a good reflector, so that the light travelling upwards from the arc is not lost but is reflected downwards.

In order to prevent the arc running up the carbons, and to spread it out into a flame-like form, the electro-magnet M is provided, and the current passing through the arc also passes through the coil of this electro-magnet. The direction of the magnetic field produced is transverse to the arc. On p. 38 it was seen that a conductor carrying a current experienced a lateral force when placed at right angles to a magnetic field. The arc is such a

conductor, and it will be seen from the left hand rule (p. 39) that with the direction of current shown in Fig. 85, the magnetic field must be horizontal, and from **front** to **back** in order to force the arc downwards. Such a field is produced by a winding of the coil as shown.

Owing to the high resistance of the thin carbons, a metallic wire runs down the axis in order to reduce this resistance, which wire is volatilised as the carbons burn away. There is a striking and feed mechanism as in the ordinary arc. The colour chosen for the flame arc is usually a slightly reddish yellow, producing a cheerful and brilliant effect, appropriate for outdoor lighting.

Efficiency of arc lamps.—Owing to the high temperature of the electric arc, the real efficiency of these lamps is generally higher than that of incandescent lamps. It must be remembered that the intensity of illumination in different directions may vary greatly in the case of an arc lamp, and the following figures are only approximations. An ordinary open arc lamp taking 12 amperes at 60 volts will probably have a candle-power of about 1000, giving an efficiency of the order of 0·8 watt per candle-power. Enclosed arcs vary much in efficiency, but with a candle-power of 2000 the efficiency will probably be of the order of 4 candle-power per watt, while a flame arc of 3000 candle-power will probably give about 10 candle-power per watt.

Arc lamps may be run **in series** or **in parallel**, according to circumstances. For example, it is more economical to run two arcs in series from 100 volt mains than to run two in parallel, because in parallel the total current for the two would be twice that required when they are in series, and, moreover, in series only half the resistance (p. 90) would be necessary. The energy drawn from the mains is therefore used up more efficiently

when the two lamps are in series than when they are in parallel.

The "pointolite" lamp.—For use in projection lanterns the arc lamp is desirable, because the emission of light takes place chiefly from a very small area, the crater. In some cases a less powerful source is desirable, but the incandescent lamp is unsuitable, because the extended filament does not enable a uniform field of illumination to be obtained. To get over this difficulty the Edison and Swan Electric Co. make a lamp which is a combination of the incandescent and the arc forms, which they call the "**pointolite**" lamp.

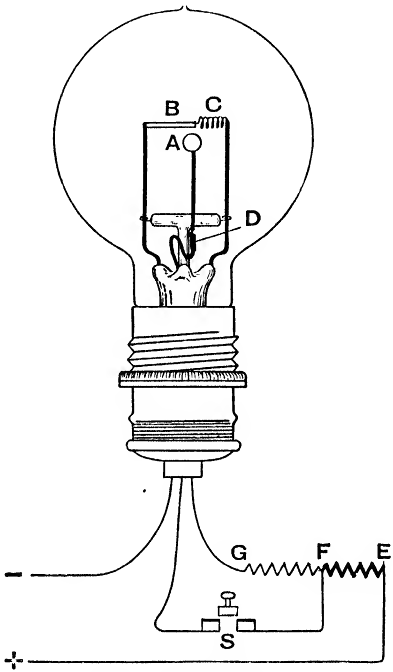

FIG. 86.—Pointolite lamp.

When the lamp is running, an arc passes from a solid sphere of tungsten A (Fig. 86) to a conductor B, and the heat produced is sufficient to maintain the sphere white hot. The sphere is thus the source of light, and in this sense the lamp is of the incandescent type. But since the high temperature is maintained by the arc, the lamp may be considered to be of the arc type.

There are several points of interest in the construction

of the lamp. For the purpose of steadying the arc, a separate resistance EFG (Fig. 86) is provided, which must have a value to suit the voltage of the supply.

In order to strike the arc, a switch S is closed temporarily, which cuts out the part of the resistance FG, so that there is a considerable p.d. between the tungsten spiral C and the sphere A. Since the bulb contains nitrogen at low pressure a current begins to flow, because the gas becomes conducting fairly easily at low pressure. The current once started, it will continue to flow for less p.d. than at the start, and on opening the switch S the arc continues.

At the high temperature of the arc the tungsten spiral would soon waste away, but there is an ingenious device for preventing this. The tungsten sphere A is carried by a metal stem, and at one end, a part of this about 1 cm. long, shown at D, is composed of two different metals which expand by different amounts on becoming hot. The result is that when the current passes, D is heated, and the unequal expansion of the two sides of the strip cause it to bend, and this moves A towards the part B. At this part the tungsten wire is covered with a non-metallic conducting tube and the arc passes between this tube and A. This non-metallic tube does not wear away appreciably and the life of the lamp is therefore considerably extended. When the current is switched off, D cools and becomes straight again, so moving A back to its position near the spiral C, ready for the restarting of the lamp.

The pointolite lamp is not usable on alternating current supply. It is made in sizes from 30 candle power, with certain modifications, to 2000 candle power, and has an efficiency of about one candle-power per watt.

The electric furnace.—The high temperature obtainable by means of the electric current has made possible many chemical and metallurgical processes previously unattainable. Thus the arc itself has been used for the process of welding and cutting through steel bars and plates. The flame of the arc can be directed upon the metal to be melted, by means of a magnet, as in the case of the

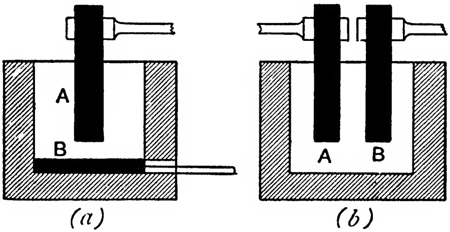

FIG. 87.—Electric furnace.

flame arc (p. 95). In other cases the arc may be produced inside the furnace, or even inside the crucible in which the materials to be melted are contained.

There are many types of furnace in which the arc is used for the production of high temperature. In Fig. 87(*a*) one carbon (*B*) constitutes one wall or the floor of the furnace, the other (*A*) is brought into contact with it and then separated from it, thus striking the arc. In Fig. 87(*b*) the two carbons *A* and *B* are similar in shape but are independent of the walls of the furnace. The temperatures attained in these furnaces are much higher than can be produced by combustion. They have made possible the production of many metals of high melting point, in compact masses. The metal chromium, now used in making certain kinds of steel, is produced in this type of furnace.

The material **carborundum**, which is a combination of carbon and silicon, and is nearly as hard as diamond, is

made in an electric furnace differing slightly from the above. Between graphite terminals *A* and *B* (Fig. 88) is a core of granulated graphite *C*. Graphite is a hard form of carbon, and is used as the black-lead in ordinary "lead" pencils. Around the core *C* is placed a mixture of coke and sand. The current in passing through the core *C* raises the temperature so much that the carbon

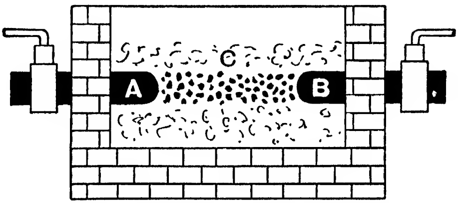

FIG. 88.—Furnace for making carborundum.

of the coke robs the sand of its oxygen. Sand is oxide of silicon, and the chemical reaction may be represented thus,

$$C_2 + SiO_2 = 2CO + Si.$$

The silicon (Si) forms with the remaining carbon the material carborundum, which, on account of its hardness, is used for making such things as grindstones and grinding wheels of the highest quality.

Another substance made in the electric furnace is calcium carbide, commonly called "carbide." This substance is a compound of calcium and carbon, which in contact with water gives off the gas acetyline, so largely used for illuminating purposes. A mixture of coke and quicklime or calcium oxide is heated in the arc type of furnace (Fig. 87). The coke robs the calcium oxide of its oxygen, and the remainder of the coke combines with the calcium to form calcium carbide.

EXERCISES ON CHAPTER IX.

1. Describe how an arc can be produced. What is the most suitable material to use in producing an arc ? Why is this ?

2. Give a sketch of some simple form of hand-feed arc lamp.

3. Why is a resistance always placed in series with an arc lamp ? What resistance would you use with an arc carrying 10 amperes, placed between 100 volt mains ?

4. Describe the action of a solenoid upon a soft iron core. How would you investigate this action ?

5. Describe the principle upon which an automatic arc regulator may be constructed.

6. Give a sketch of the mechanism of some form of automatic arc lamp.

7. Distinguish between the open arc and the enclosed arc, and give the advantages of the latter.

8. Describe some form of flame arc, pointing out carefully how it differs from the ordinary arc.

9. Describe some form of electric furnace, and the use to which it is put.

10. Give a diagram of the arrangement you would use for measuring the power absorbed by an arc lamp.

CHAPTER X

CELLS AND BATTERIES

Chemical action.—In order to understand the principles of electric cells, the simplest types of chemical action must be comprehended. All substances consist of **atoms**, and when these atoms are all of one kind the substance is called an **element.** When one or more atoms of one element combine with one or more atoms of another element, a **molecule** of some new substance called a **compound** is produced. Thus, one atom of the element oxygen (O) can combine with two atoms of the element hydrogen (H) to form a molecule of the compound water (H_2O). This process may be represented by an equation thus,

$$H_2 + O = H_2O.$$

Again, carbon (C) and oxygen combine to form the gas carbondioxide, or carbonic acid,

$$C + O_2 = CO_2.$$

These two reactions nearly always occur when there is combustion or burning.

There are two large classes of compounds, known respectively as **acids** and **salts**, which play a most important part in electrical effects. As a typical acid take hydrochloric acid (HCl), which is a compound of hydrogen and chlorine (Cl). If the hydrogen in hydrochloric acid

be replaced by a metal, a salt is produced, in this case called a **chloride**. Thus, sodium (Na) and chlorine form sodium chloride ($NaCl$), known as common salt. Potassium (K) and chlorine form potassium chloride (KCl). Zinc (Zn) and chlorine form zinc chloride ($ZnCl_2$). Another acid is nitric acid (HNO_3), which gives rise to nitrates, sodium nitrate ($NaNO_3$), potassium nitrate (KNO_3), known as nitre, and zinc nitrate ($Zn(NO_3)_2$).

Sulphuric acid (H_2SO_4) gives rise to sulphates, such as sodium sulphate (Na_2SO_4), potassium sulphate (K_2SO_4), zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$).

Electrolysis.—All the substances named above will dissolve in water, and the solution formed will conduct electricity. Pure water is almost a non-conductor, but is rendered conducting by dissolving one of these (or many other) salts or acids in it. Such a solution is called an **electrolyte**.

The conducting wires or plates by which the current is led into or out of the electrolyte are called **electrodes**, that by which it enters is the **anode** and that by which it leaves is the **kathode.**

When a current passes through an electrolyte **chemical action always occurs.**

The **metal** or **hydrogen** is liberated at the **kathode**, that is, **where the current leaves**. The **acid part**, that is Cl, NO_3, or SO_4 is liberated at the **anode**, that is, **where the current enters.** It does not follow that the substance liberated can be seen or collected. For example, if the electrolyte is a solution of sulphuric acid (H_2SO_4), the hydrogen is liberated at the kathode and forms bubbles, which may rise up to the surface, but the SO_4 cannot exist alone. It immediately attacks the water and forms sulphuric acid again with the hydrogen. The oxygen is

liberated and forms bubbles on the anode. This reaction can be represented as follows,

$$H_2O + SO_4 = H_2SO_4 + O.$$

EXPT. 30. **Electrolysis.**—Procure two beakers, and into one of them place a dilute solution of sulphuric acid, into the other a solution of copper sulphate (blue vitriol). Connect them in series as in Fig. 89 and pass a current through them from four dry cells in series, using carbon rods for the electrodes *ABCD*. Then *B* and *D* are kathodes and *A* and *C* anodes. It will be seen that bubbles form on *A* and *B*, but more quickly on *B* than on *A*. By means of an inverted test tube filled with the solution as shown, the bubbles from *B* may be collected. When the test tube is full, on applying a light to the mouth of the tube, the gas will burn with a blue flame. It is hydrogen. If the bubbles from *A* be collected, the gas will not burn, but if a glowing taper be plunged into it the taper will burst into flame and burn brilliantly, showing that the gas is oxygen.

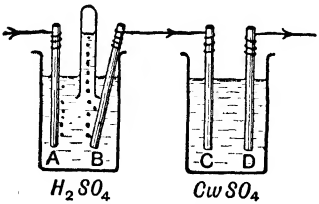

FIG. 89.—Electrolysis.

After a short time the kathode *D* will be seen to be covered with a red deposit, which is metallic copper, while the anode *C* is unaffected.

Reverse the current, and notice that the hydrogen will now be deposited upon *A* and oxygen upon *B*, while the copper will be deposited upon *C* and dissolved from *D*.

Copper voltameter.—A very important use to which electrolysis has been applied is the measurement of electric current, by the amount of deposition it causes. It is known from careful measurements that 1 ampere flowing for 1 second deposits 0·000329 gram of copper from copper sulphate. This quantity is called the

electro-chemical equivalent of copper. The electro-chemical equivalent of any other substance can be found, but this will not be discussed further here.

Since 1 ampere deposits 0·000329 gram of copper in 1 second, it follows that for any other current,

$$\text{Wt. of copper deposited} = 0{\cdot}000329 \times \text{current} \times \text{time},$$

or, $$\text{Current} = \frac{\text{Wt. of copper deposited}}{0{\cdot}000329 \times \text{time in seconds}}.$$

The cell in which the electrolysis occurs is called a **voltameter**, and it is commonly used for standardising ammeters. This method is a very good and very convenient one, since all the materials are easily obtained, the only delicate apparatus required being a good balance.

It should be noticed that the strength of the solution of copper sulphate is not changed by the passage of the current. For, the process may be represented thus,

$$\text{Cu SO}_4 = \underset{\text{(at kathode)}}{\text{Cu}} + \underset{\text{(at anode)}}{\text{SO}_4}$$

The SO_4 liberated at the anode cannot exist alone, and with the copper plate forms copper sulphate thus,

$$\text{SO}_4 + \text{Cu} = \text{Cu SO}_4.$$

Thus the anode is continually being dissolved and the kathode is built up, but the increase in weight of the kathode alone must be taken in measuring current by means of the voltameter.

Expt. 31. **To standardise an ammeter by means of the copper voltameter.**—In a jar or beaker place a strong solution of copper sulphate, with a few drops of sulphuric acid added. In the solution suspend three thin pieces of sheet copper *A*, *B* and *C* (Fig. 90) from brass rods, *A* and *B* being connected in parallel. By means of a battery of four dry cells or two storage cells pass a current through the copper sulphate solution, the ammeter *G* and the rheostat *R* in series. Care must be taken that the current enters the voltameter by the

plates A and B and leaves by C. By means of the rheostat, adjust the current until the value is that corresponding to the reading of the ammeter that it is required to check: say 0·8 or 1·0 ampere. Stop the current by removing the plug from the key K, remove the plate C, wash it in clean water, and dry it by moving it about in the warm air over a spirit lamp flame. It may be merely left to dry if time is no object, but, on the other hand, it must not be dried by heating too much; it should never be placed in the flame itself. After it has cooled, weigh it carefully and record the weight. Then replace the plate in the voltameter. Put the plug in the key K, noting the time that this is done by means of the second hand of a watch or clock. Let the current flow for about half-an-hour, or longer if convenient, keeping the current steady by means of the rheostat if any variation is apparent. At the end of this interval take out the plug, noting the time. Remove, wash, dry and weigh the plate as before.

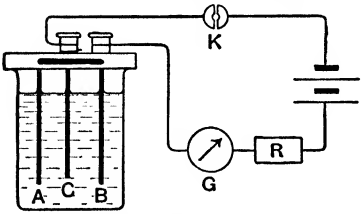

FIG. 90.—Copper voltameter.

The gain in weight of the plate, divided by 0·000329 and by the interval of time in seconds for which the current flowed, is then the current. If this is identical with that indicated by the ammeter there is no error of the instrument, but if it is not, the difference of the two is the error of the instrument at this point on the scale. The errors at other parts of the scale may be found in a similar manner and recorded.

EXAMPLE.—The kathode of a copper voltameter weighs 12·47 grams when the current is started at 7h. 15m. 27sec. and 13·22 grams when the current is stopped at 7h. 58m. 14sec. If the ammeter reads 0·9 amp. throughout this interval what is the error of the instrument?

$$\begin{array}{lrl} & \text{Wt. at 7 h. 15 m. 27 sec.} = & 12{\cdot}47 \text{ grams} \\ & \text{Wt. at 7 h. 58 m. 14 sec.} = & 13{\cdot}22 \text{ grams} \\ \hline \therefore \text{ gain in} & \text{42 m. 47 sec.} = & 0{\cdot}75 \text{ gram} \\ \hline & \text{42 m. 47 sec.} = & 2567 \text{ seconds} \end{array}$$

$$\text{Current} = \frac{0{\cdot}75}{0{\cdot}000329 \times 2567}$$
$$= \underline{0{\cdot}888 \text{ ampere}};$$

$$\therefore \quad \text{Error of ammeter} = 0{\cdot}888 - 0{\cdot}900$$
$$= \underline{-0{\cdot}012 \text{ amp. at } 0{\cdot}9 \text{ amp.}}$$

Simple voltaic cell.—The earliest type of battery was constructed by Volta, and consisted of alternate plates of copper and zinc, but with cloth moistened with acid placed between the plates in such a way that the pile was made up in the order, copper-acid-zinc-copper-acid-zinc,and so on. Each element of this pile or battery consists of a cell of the form copper-acid-zinc.

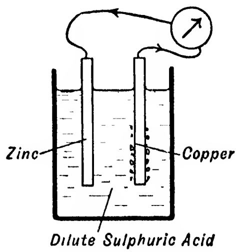

FIG. 91.—Simple voltaic cell.

On dipping a zinc rod and a copper rod into dilute sulphuric acid as in Fig. 91, and connecting them by a wire with a simple galvanometer in circuit, a current will flow in the direction shown. That is, it will leave by the copper electrode and enter by the zinc. The copper is therefore the kathode, and hydrogen bubbles will be seen to form on it (p. 104). The SO_4 is liberated at the anode, that is the zinc, and with it forms zinc sulphate, which dissolves in the water.

$$Zn + SO_4 = Zn\,SO_4.$$

Various substances such as carbon or platinum may be used instead of the copper, and iron may replace the zinc, but the effect is similar to the above. The e.m.f. of the cell will vary, however, according to the substances used. The copper, carbon, or platinum will be the

positive pole of the cell, and the zinc or iron the **negative pole**.

Polarisation.—The simple cell as described above is not very efficient. The current obtainable is not great, and falls off very rapidly. On seeking for the cause of this falling off of the current, it is found in the hydrogen deposited upon the positive electrode. This hydrogen not only increases the resistance of the cell but also lowers its e.m.f. When this effect takes place the cell is said to be **polarised**, and it is with the intention of removing or preventing the formation of this hydrogen which produces polarisation that other forms of cell have been devised. Only the most important of such cells will now be described. Others, such as the Bunsen cell, the Grove's cell, and the bichromate cell, are rarely met with now, as the public supply of electricity has rendered them obsolete. Nevertheless there is a great use for cells for such purposes as bells, telephones, and flash lamps, and for standards of electromotive force, where the amount of current required is only small.

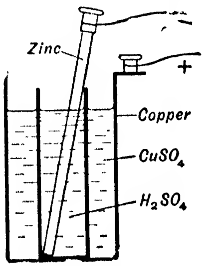

FIG. 92.—Daniell's cell.

Daniell's cell.—Where a small supply of current, at fairly constant e.m.f., is required, the Daniell's cell, Fig. 92, is frequently used. The copper electrode may form the outer vessel as shown, or an earthenware jar may be used, into which a piece of sheet copper is placed. In either case, the vessel contains a strong solution of copper sulphate. In this stands a porous pot of unglazed earthenware, which contains dilute sulphuric acid, with a zinc rod to form the negative electrode, dipping into it. The two solutions soak into the porous

pot and there come into contact, but the pot prevents their rapid mixing. The reactions at both electrodes have already been described. At the positive, copper is liberated (p. 104), and at the negative, SO_4 is liberated, which attacks the zinc, forming zinc sulphate, which dissolves. Thus the copper electrode is being built up all the time the current flows, while the zinc electrode is being dissolved away. Thus there is no hydrogen formed on the positive electrode, and therefore there is no polarisation. On this account the e.m.f. of the Daniell's cell is very constant. It is about 1·1 volt.

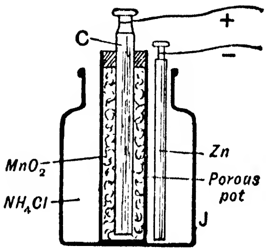

FIG. 93.—Leclanché cell.

Leclanché cell.—The most commonly used cell is of the **Leclanché** type, in which the positive electrode is a rod of carbon *C* (Fig. 93), and the negative electrode is a rod of zinc. The electrolyte contained in the glass jar *J* is a strong solution of ammonium chloride, or salammoniac (NH_4Cl). When the current passes, the chlorine (Cl) is liberated on the zinc, forming zinc chloride ($ZnCl_2$). On the carbon NH_4 is liberated, but this is a substance which cannot exist alone and breaks up into ammonia (NH_3) and hydrogen.

$$2NH_3 = 2(NH_3) + H_2.$$

The cell rapidly becomes polarised by this hydrogen, and it is therefore necessary to remove it. In order to do this some material rich in oxygen is provided, so that the oxygen will combine with the hydrogen, forming water. The material employed is manganese dioxide (MnO_2), which will easily part with some of its oxygen, thus,

$$2MnO_2 + H_2 = H_2O + Mn_2O_3.$$

The manganese dioxide is a black powder, and is mixed with powdered gas carbon and packed into the porous pot (Fig. 93) so that it surrounds the carbon rod. Therefore, on producing current, the cell rapidly polarises, owing to formation of hydrogen upon the carbon positive rod, but, on standing idle, the manganese dioxide removes this hydrogen and the cell recovers its original voltage. Hence, the cell is very useful where currents are only used for a short time, and there are intervals of rest. For electric bells, telephones, etc., this type of cell is generally used.

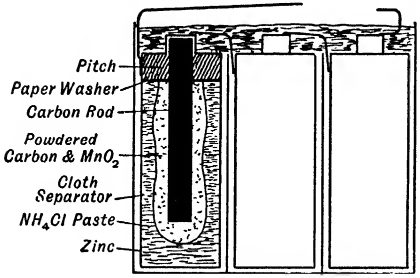

FIG. 94.—Battery of dry cells for flash lamp.

The e.m.f. of the Leclanché type of cell is about 1·5 volt.

Dry cells.—When the cell is kept out of the way in one fixed position, the type shown in Fig. 93 is very convenient, but when it is to be moved about, the splashing of the liquid is objectionable. To get over this difficulty the **dry cell** has been produced. In the sense of no liquid being present, a dry cell is of course impossible, but in the so-called dry cell, the ammonium chloride is made into a paste with sawdust, glycerine and some material such as calcium chloride, which absorbs moisture and keeps the paste from drying. In Fig. 94 is shown a battery of three such cells, known as a 4 volt battery, such as is used in the common pocket flash lamp, one of the cells being shown in section. The outer case of each cell is made of zinc and acts as the negative electrode.

The carbon positive rod is surrounded by powdered carbon and manganese dioxide, held together by a piece of cloth tied round it. This cloth plays the part of the porous pot in the ordinary type of Leclanché. Between the cloth and the zinc is a paste of ammonium chloride. The contents of the cell are saturated with water, but, being in a pasty form, there is no free liquid. Each cell is covered with a paper washer, and the whole battery is cemented up with some form of insulator such as pitch or marine glue.

There are many larger forms of dry cell, but they are all varieties of the above type.

Amalgamation of zincs.—Ordinary commercial zinc contains many impurities, the most important of which is iron in small particles. When the liquid of the cell comes in contact with the zinc, a local cell is formed of the zinc and metal impurity, in contact with the liquid. The zinc will therefore be dissolved (p. 107), and a hole formed wherever there is any such impurity. This process leads to a great waste of zinc, and the rod is dissolved away rapidly.

In order to avoid this destruction of the zinc it is usual to cover the electrode with a layer of mercury, that is, to **amalgamate** the zinc. The mercury dissolves the zinc and forms a layer covering over the impurities. Thus the local action of the impurities is stopped, but since the zinc dissolved in the mercury is in contact with the liquid of the cell, the cell continues to work, and the zinc is only dissolved during the proper production of current by the cell.

Standard cell.—For maintaining a standard of electromotive force, it is desirable to have some cell which can be constructed in such a way that its e.m.f. is definitely known. The cell chosen for this purpose is known as

the **Weston cell** or **cadmium** cell, and is constructed of the purest obtainable materials. One pattern of the cadmium cell is shown in Fig. 95. The materials are contained in a glass vessel shaped somewhat like the letter H. The terminals consist of platinum wires sealed into the glass and passing into the electrodes. The positive electrode is a pool of mercury, and upon this rests a paste of mercurous sulphate, and upon this is a layer of cadmium sulphate crystals. The negative electrode consists of cadmium amalgam (solution of cadmium in mercury), and upon this is a layer of cadmium sulphate crystals. The two limbs are connected by a solution of cadmium sulphate which fills the cross-piece of the tube.

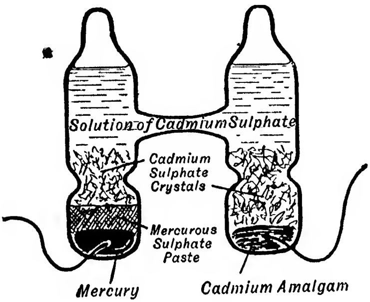

FIG. 95.—Standard cell.

Such a cell has an electromotive force of 1·0183 volt at a temperature of 20° C., and at any other temperature the e.m.f. may be calculated from the equation

$$\text{e.m.f.} = 1{\cdot}0183 - 0{\cdot}0000406\,(t - 20) \text{ volt,}$$

where t is the temperature on the centigrade scale.

Care must be taken that only very minute currents are produced by the standard cell, or it will be ruined as a standard. For this reason it is usual to connect up permanently a resistance of several thousand ohms in series with the cell.

Storage cells or accumulators.—It has been seen (p. 104) that when a current passes through dilute sulphuric

acid, oxygen is liberated at the anode. If the anode is a lead plate, the oxygen attacks the lead, forming lead oxide (PbO_2), and if the kathode is also a lead plate the hydrogen liberated bubbles away. The experiment may be performed as shown in Fig. 96, the two lead plates *G* and *H* dipping into a beaker of dilute sulphuric acid. On putting plugs into the keys at *A*, *E* and *F*, current flows from the plate *H* to the plate *G*, and *H* therefore becomes oxydised. There is now an electromotive force due to the cell *GH*, *H* being the positive electrode. On removing the plug from *A* to *B*, the electric bell *K* will ring for a short time. The cell *GH* is called a **storage cell or accumulator**, because current can only be obtained from it after current has been passed through it from some other source of current. That is, the cell has to be **charged** before it can be **discharged.**

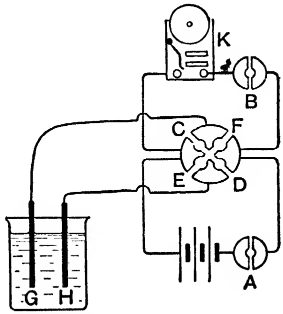

FIG. 96.—Experiment to illustrate storage by a cell.

Forming the plates.—The capacity of the accumulator is very small on first charging it, but it can be increased very much by passing the current through the cell alternately in opposite directions for a number of times. After charging, with the plugs in *A*, *E* and *F*, if the plugs are removed from *E* and *F* and placed in *C* and *D*, the current now passes into the cell at the electrode *G* and out at *H*. The cell at first helps the current, but when its discharge is complete, the current will begin to oxidise *G* and make this the positive and *H* the negative. At the next reversal *H* again becomes the positive. On continuing this process the storage capacity increases, because the layer of oxide formed on the plates becomes

thicker and thicker. This process is called **forming** the plates. After several of these reversals it will be found, on removing the plug from *A* to *B*, that the bell will ring for a much longer time than it would after the first charging.

Use of accumulators.—Accumulators are used when cells capable of giving large currents are required. The lead plates are of considerable area and are placed alternately + and −, the positive plates being welded to a lead bar *B* (Fig. 97), at the top of the cell, above the liquid, while the negative plates are similarly connected to a bar *A*. The plates rest on bars, *D*, of wood, soaked in paraffin wax, and are held apart by separators *G*, which are usually glass tubes. Owing to the small distance apart of the plates, and their great area, the resistance of accumulator is very small, and on this account the current obtainable from an accumulator is great. The e.m.f. of an accumulator is 2·1 volts until it is nearly discharged, when the e.m.f. runs down rapidly.

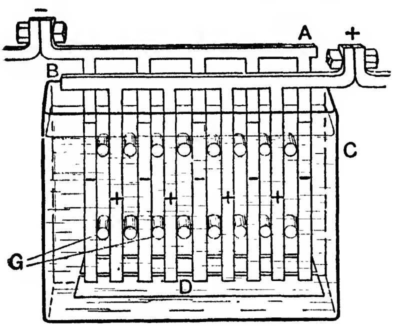

Fig. 97.—Storage cell.

Example.—A given Daniell's cell has e.m.f. 1·1 volt and internal resistance 1·5 ohm, while a given accumulator has e.m.f. 2·1 volts and internal resistance 0·01 ohm. What is the greatest current obtainable from each of these cells ?

Since the greatest current is obtained when the resistance of the circuit is least, we must imagine each of the cells to be short circuited by a piece of stout copper wire of practically zero resistance.

Then from equation (5) on p. 57.

For the Daniell's cell,

$$\text{current} = \frac{1 \cdot 1}{1 \cdot 5}$$
$$= \underline{0 \cdot 73 \text{ ampere.}}$$

For the accumulator,

$$\text{current} = \frac{2 \cdot 1}{0 \cdot 01}$$
$$= \underline{210 \text{ amperes.}}$$

It should be noted that although the accumulator would give this current for a short time, this must not be allowed, as the cell would probably be injured. Still, large currents may be obtained without injury to the cell.

Types of accumulator plates.—The storage capacity of an accumulator depends upon the area of plate in contact with the liquid. For this reason plain lead sheets are never used, but the plates are made in grids or lattices of various patterns. Fig. 98 (*a*) illustrates a common type of positive plate. Strips of lead are burnt into a framework so that the liquid can percolate between the strips. *A* and *B* are lugs by which the plates rest on the edges of the containing vessel, and *C* is the strip which is bolted to the corresponding strip of the next cell. Fig. 98 (*b*) shows the type used in the "chloride" cell for the positive plates. Small dented strips of lead are rolled into spirals and pressed into holes in the lead plate. One such strip is shown partially unrolled at *D*.

A method of shortening the process of forming the plates (p. 113) consists in making the plate in the form of an open grid, and into the open parts of the grid pressing a paste of red lead (Pb_3O_4) and sulphuric acid. The process of forming is then considerably shortened, because the lead is already partly oxidised, and the oxide is already porous. Such plates are called **paste** plates. Paste plates are not so durable as formed plates. Since the

positive plates are much more liable to deterioration than the negative plates, some manufacturers use formed plates for the positives and paste plates for the negatives. Fig. 98 (*c*) and (*d*) show the framework of the negatives used in different types of E.P.S. accumulators. The sections shown are taken through the plane *e* in each case.

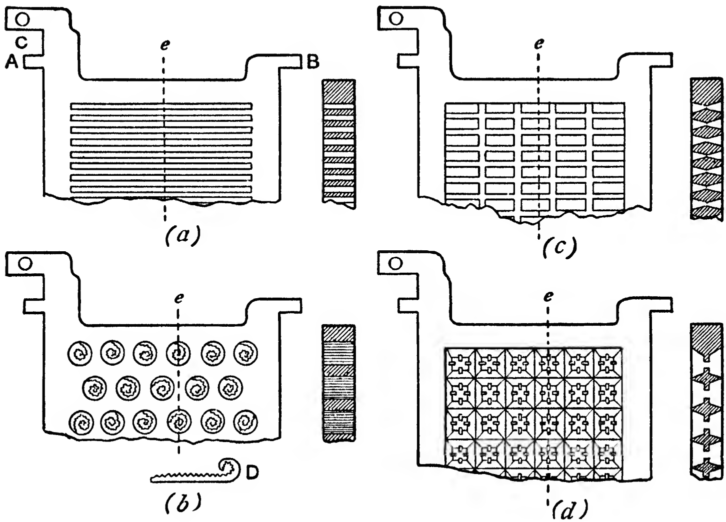

FIG. 98.—Accumulator plates.

Use of accumulators.—Storage batteries are generally used in conjunction with dynamos (Chap. XII.) or supply for lighting and other purposes, when it is not convenient to run the dynamo continuously. The battery is charged periodically by means of the dynamo, and the actual supply is taken from the cells. Since the e.m.f. of an accumulator rises to 2·3 or 2·4 volts during charge and falls to below 2·0 volts during discharge, the supply voltage would vary considerably unless some means of regulation were employed. For this purpose certain

cells at the positive end of the battery are connected up to the studs *a b c d e* (Fig. 99) of the switch *S*. In this way any number of cells from 50 to 55 may be put in the circuit. When the battery is fully charged, the switch may be placed at *a*, so that only 50 cells are in use. As the voltage drops, the cells, 51, 52, etc., are brought in by means of the switch, so that the voltage may be maintained at a nearly constant value. If the charging dynamo is to be run at the same time as the battery is

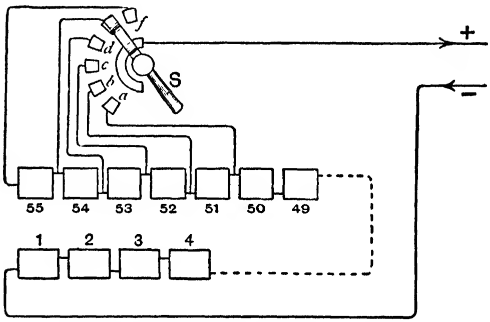

FIG. 99.—Arrangement of storage battery.

supplying current, a double switch is used so that the number of cells being charged may be regulated at the same time as the number being discharged.

The arrangement of Fig. 99 is suitable for supply at 100 volts, and with seven positives and eight negatives in each cell a charging current of 50 amperes for 6 hours is suitable. The capacity of the battery is thus said to be $50 \times 6 = 300$ **ampere-hours.** The rate of discharge may exceed this; thus the battery may be discharged at 80 amperes in $3\frac{3}{4}$ hours or at 100 amperes in 3 hours. But it should be noted that about 20 per cent. of the quantity put in during charge is lost and cannot be recovered, even when the discharge is at a small

current, and this loss is greater when heavier currents are used.

Care of accumulators.—An accumulator should never be completely discharged, as the lead oxide with the sulphuric acid forms hard insoluble lead sulphate, which cannot be decomposed on charging. The plates begin to flake, and pieces dropping between the plates short-circuit the cell and complete its destruction. Also, the cells should not be overcharged. When fully charged the oxygen deposited on the positive plates no longer oxydises the lead (p. 113), and bubbles up, making the liquid have a milky appearance. There are two guides to the condition as regards charge of a cell.

Fig. 100. Hydrometer.

(i) **The voltage**, which should never be below 2·3 at full charge or fall below 2·0 on discharge.

(ii) **The density of the liquid**. The density of the liquid rises during the charging of the cell, owing to the liberation of sulphuric acid, and falls during the discharge owing to absorption of sulphuric acid. For observing the density a **hydrometer** (Fig. 100) is the most useful instrument. This is a vertical tube, weighted at the bottom, with a vertical scale, so that the depth to which it floats in the liquid indicates the density. The scale generally extends from 1·120 to 1·250, usually marked 1120 and 1250. When the cell is fully charged, the density of the liquid should be 1·210, and it should never fall below 1·170 during discharge.

The density and voltage for each cell should be observed periodically and recorded, if the battery is to be maintained in a healthy condition.

The Edison accumulator.—In recent years an accumulator has been devised by Edison, in which neither lead

nor sulphuric acid is used. The positive electrode consists of nickel hydrate packed into a nickel tube, the negative electrode of finely divided iron oxide contained in pockets of nickel steel, and the electrolyte is a solution of potassium hydrate.

One of the positive plates is shown in Fig. 101, consisting of 30 nickel-steel tubes held in a nickel-steel

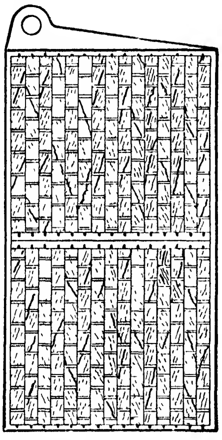

FIG. 101.—Positive plate of Edison accumulator.

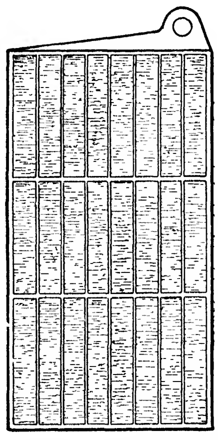

FIG. 102.—Negative plate of Edison accumulator.

frame. Each tube is formed of a perforated strip bent into a spiral and held together by 8 steel bands. The tube is filled with a mixture of nickel hydrate and flakes of metallic nickel. The purpose of the latter is to increase the conductivity, and so convey the current to the inner layers of the mixture.

In Fig. 102 is shown one of the negative plates, consisting of 24 pockets of thin perforated nickel-steel strips. The finely divided iron oxide is contained in these pockets, being compressed into a compact mass. The plates are

assembled as in the case of the lead accumulator and are mounted in a nickel-steel case, being insulated from it and the positives from the negatives by ebonite separators. The case is completely closed, but has a valve at the top which allows gas to escape but does not allow air to enter.

The e.m.f. of the Edison cell is lower than that of the lead accumulator, being about 1·2 volt during discharge. The great advantage of the Edison cell over the lead accumulator is due to the strong mechanical structure of the plates, which enable it to undergo treatment which would destroy the plates of the latter. For example, it may be completely discharged without injury, and may even be left for months completely discharged without suffering deterioration. It is therefore coming into use for purposes of electric traction and in places where the constant expert attention required by the lead accumulator is not available.

Electroplating.—Before leaving the subject of electrolysis, one very important application of it must be mentioned. That is the deposition of the rarer metals upon common metals, both for purposes of preservation and for appearance. This process is called **electroplating,** and the most common form of the process is that of depositing silver upon the commoner metals such as copper or nickel.

One example of electroplating has already been given, namely, the deposition of copper upon carbon (p. 104) or copper (p. 105). If in Expt. 31 the current is great, the copper deposited is soft and is easily rubbed off the plate. But if the current does not exceed one ampere for every 50 square centimetres of the kathode immersed in the solution, the deposit is hard bright metallic copper. If instead of the copper plate used for the kathode, iron or any similar metal be employed, it may be electroplated

with copper in this way. Great care must be taken in cleaning articles to be electroplated: they must be thoroughly scrubbed with sand or with wire brushes, and washed in dilute sulphuric acid.

The process of **electrotyping** is another application of electrolysis. When a page of print is set up in type, wax is pressed on to the type by hydraulic pressure, the type first having been sprinkled with powdered graphite to prevent the wax from sticking to it. The wax, on being removed, forms a mould, and on the surface of it graphite is powdered, in order to render the surface electrically conducting. Copper is now deposited upon it by making it the kathode in a copper sulphate bath. When a hard layer of copper is formed, the wax is removed and molten type metal poured into the copper shell to strengthen it. The plate so formed is a good copy of the original type, and is used for the actual printing. This process provides permanent plates of the pages of books and releases the type for further use.

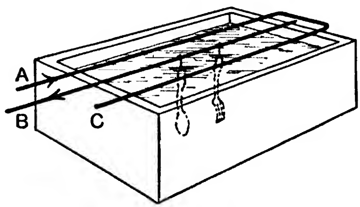

FIG. 103.—Silver-plating bath.

(Another important application of electrolysis is the process of **silver-plating.** In this case the liquid used must be a solution of a silver salt. The best results are obtained by using a solution of the double cyanide of silver and potassium. To a solution of silver nitrate is added potassium cyanide. At first a heavy white precipitate is obtained, but, on continuing to add potassium cyanide, the precipitate is dissolved, giving a solution suitable for silvering. This solution is placed in the silvering bath, Fig. 103. The articles to be silvered are

suspended from the metal rod *B* by wires, after having been cleaned, by scrubbing with wet sand or a wire brush, washing in strong soda and then clean water. The rods *A* and *C* are connected together and from them are suspended plates of silver. The current is passed in through *A* and *C* and out through the articles to be silvered and the rod *B*. As deposition occurs on the articles which constitute the kathode, so the silver plates which constitute the anode are dissolved away, in a manner similar to that of the copper plates in Expt. 31. The strength of the solution thus remains constant. After the deposition is complete, the articles are removed, washed and burnished to give them the usual bright appearance.

Electro-metallurgy.—Of the innumerable applications of electrolysis to the production of metals only two will be described here, these two being of incalculable importance.

The metal **copper** has very high electrical conductivity, but slight traces of impurities cause a great falling off in conductivity. On account of this it is very important to obtain nearly pure copper for the manufacture of electrical conductors. The copper obtained by the ordinary process of smelting contains impurities which render it unfit for these purposes, and it is therefore purified by electrolysis. The impure copper is cast into slabs, which are placed as anodes in an electrolytic cell of which the liquid is a solution of copper sulphate and the kathode is a plate of pure copper. On passing the current, the copper of the anode dissolves (p. 105), and very nearly pure copper is deposited upon the kathode. In places where electrical power can be obtained cheaply this process has become of great importance commercially.

Another metal which has now acquired great import-

ance is **aluminium**, but it can only with great difficulty be obtained by chemical means from the oxide of aluminium or alumina, which is the basis of clay. The clay is mixed with another mineral containing aluminium and sodium. The current is passed through the molten mixture, and the aluminium is deposited at the kathode. The molten mixture, which is really a solution of alumina in sodium and calcium fluorides, is contained in a bath lined with carbon, into which dips a carbon rod which acts as anode. The aluminium is deposited on the walls of the bath and collects into drops, which, as they coalesce, can be run off from the bottom, while fresh alumina is fed into the top of the cell. The process is thus continuous, as, once started, the heat produced by the current is sufficient to maintain the contents in the molten state.

EXERCISES ON CHAPTER X.

1. Describe what you mean by 'electrolysis,' giving the terms usually employed.

2. How do the metals and the acids differ in their behaviour when an electric current passes through a solution containing them ?

3. What is the copper voltameter, and how is it used to standardise an ammeter ?

4. Describe the simplest form of electric cell with which you are acquainted ?

5. What is meant by the polarisation of a cell, and how may it be avoided.

6. Describe some form of Leclanché cell, and state the purposes for which it is suitable.

7. Describe, with sketch, the dry cell.

8. Why is it desirable to amalgamate the zincs used in cells ?

9. What is a storage cell or accumulator ? How may a simple accumulator be made ?

10. Explain how it is that a very much larger current may be obtained from an accumulator than from a Daniell's cell.

11. Describe, with sketches, some of the forms of the lead plates used in accumulators.

12. State all you know concerning the care of accumulators.

13. Describe the process of electroplating in the case of silver.

14. Describe how some one important metal may be prepared by electrolysis.

15. Describe the Edison cell, and point out its advantages over the lead accumulator.

CHAPTER XI

INDUCED ELECTROMOTIVE FORCE

Production of e.m.f. by a magnetic field.—One of the most important discoveries made by Faraday is that **whenever a conductor cuts across magnetic lines of force an electromotive force is produced in the conductor.** With a strong magnetic field this effect may be seen with a single wire, as in Fig. 104. The stiff wire AB is connected in series with the galvanometer G, and is situated between the poles of an electro-magnet. If the conductor is now moved rapidly downwards there will be a deflection of the galvanometer. This deflection only lasts while the conductor is moving; directly it is brought to rest the current ceases, however strong the magnetic field may be. The e.m.f. in AB only exists while there is motion of the wire **across** the lines of force. If the wire be moved in its own direction, that is in the line AB, there is no e.m.f., because the wire is not then cutting across the lines of force.

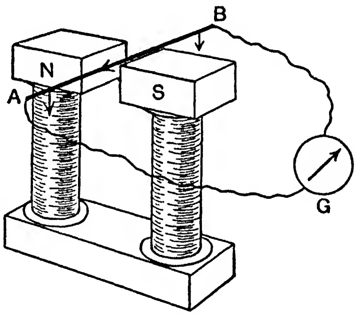

FIG. 104.—E.m.f. produced by cutting across a magnetic field.

If AB be moved **upwards** the e.m.f. acts in the reverse direction to that for the **downward** motion.

When the motion is downwards, with the magnetic poles as shown in Fig. 104, the e.m.f. is from B to A. When the motion is upwards, the e.m.f. is from A to B.

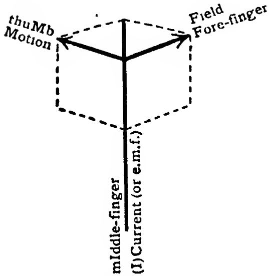

FIG. 105.—Right-hand rule for induced e.m.f.

Right-hand rule for induced e.m.f. Whenever a conductor cuts across a magnetic field, the direction of the e.m.f. may be given by a rule similar to that on p. 40, but using the **right hand** instead of the left hand. Place the thumb, fore-finger and middle finger of the **Right** hand mutually at right angles, that is, pointing along the three edges of a cube, as in Fig. 105. Then, if the

Fore-finger points along the Field,
and the **thuMb points in the direction of Motion,**
then the **mIddle finger points in the direction of the Induced e.m.f. or current.**

EXPT. 32. **Currents induced by a magnet.**—Obtain a coil of about 50 to 100 turns of wire, and connect it in series with a galvanometer (Fig. 106). Take a bar magnet and push the N pole of the magnet into the coil, and notice the sudden kick of the galvanometer, noting whether it is to the right or left. Draw the magnet quickly out of the coil and again note the kick. Repeat, using the S pole of the bar magnet. Record the results as follows :

N pole advancing	Kick to (right or left)
,, ,, receding	,, ,, ...
S ,, advancing	,, ,, ...
,, ,, receding	,, ,, ...

Now repeat the experiment with the magnet fixed, pushing the coil on to the magnet. Notice that exactly the same results are obtained as before, showing that it is the **relative motion** of the coil and the magnetic field which produces the induced e.m.f.

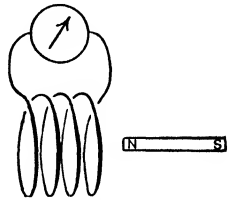

FIG. 106.—Induced current.

Rotating coil.—If the single wire *AB* in Fig. 104 be replaced by a loop of wire as in Fig. 107 (*a*), it will be seen on moving the loop up and down through a short distance, that there is no e.m.f. acting round the coil *ABCD*. The reason is that there is an e.m.f. in both *AB* and *DC* in the same direction; that is, from front to back, or from back to front. But these two e.m.f.'s are directed in opposite ways round the coil, so that they cancel each other and the result is zero.

If however the coil be rotated, as shown by the arrows, the e.m.f. produced by the motion is from *B* to *A* in the upper half, which is descending, and from *D* to *C* in the lower half, which is ascending. The result is that the e.m.f.'s are added, and a current is produced in the galvanometer.

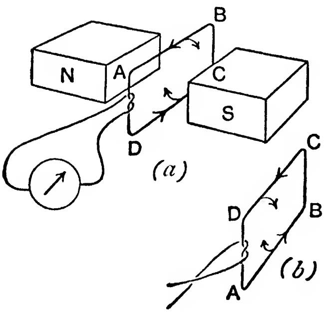

FIG. 107.—Rotating coil in magnetic field.

When one half rotation is completed, *CD* is at the top and *AB* at the bottom, as in Fig. 107 (*b*), and during the next half rotation the e.m.f., and therefore the current, will be in the reverse direction to that of the first half rotation.

If, instead of the coil being rotated, the electro-magnet

were reversed in polarity by reversing the current in its coils, the effect would have been just the same, for, in either case, the magnetic lines are first removed from the coil and then put in on the other side. This gives the first transitory current. They are next cut out and put in on the original side ; this gives the second transitory current in the reverse direction to the first.

This is a very important process, for if by **any means** the number of magnetic lines of force threaded through a circuit is caused to change, an e.m.f. will act round the circuit while the change is going on.

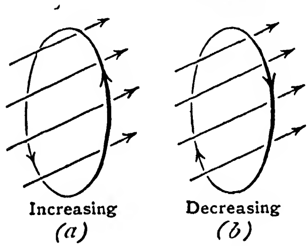

FIG. 108.—Rule for direction of induced e.m.f.

Rule for direction of induced e.m.f. in a coil.—Look at the coil in a direction which is **along the lines of force**, then, if the number of lines of force passing through the coil is **increasing**, the induced e.m.f. is **counter clockwise** (Fig. 108 (*a*)). When the number of lines of force is **decreasing** the current is **clockwise** (Fig. 108 (*b*)).

This is quite in accordance with the direction of the e.m.f. indicated in Fig. 107, and it is important to note that the rule is true whatever may be the cause of the change in the number of lines of force threaded through the coil. The cause may be a change in size of the coil or movement of the coil, or a change in strength of the magnetic field, or may be due to its movement.

EXPT. 33. **Currents induced by a current.**—Obtain two coils, one of which will slip into the other. Let the inner coil *A* be connected to a reversing key *K* and an ordinary plug key *P* as shown in Fig. 109. Connect the outer coil *B* to a galvanometer *G*. With *A* inside *B*, start the current by

inserting the plug *P*, and observe the amount of throw of the galvanometer needle. Stop the current by removing *P*, and note that there is an equal throw in the opposite direction. Record the results in a manner similar to that of Expt. 32. Repeat, first having reversed the direction of the current in *A* by means of the reversing switch *K*.

Now repeat the above experiment with a rod of soft iron inside *A*. The results will be in the same direction as before but of much greater intensity, showing that the iron, which

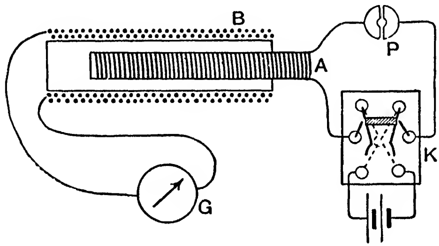

FIG. 109.—Currents induced by a current.

has greatly increased the magnetic field due to *A*, has similarly increased the induced e.m.f.

Again repeat all these experiments, but, instead of starting and stopping the current, push *A* into *B* and then remove it. The results will be exactly as before.

If instead of starting and stopping the current, or introducing and removing the coil, the current in *A* be reversed by the switch without removing the plug *P*, similar results will be obtained again, but they will be much greater than before.

Induction coil.—The principles demonstrated in Expt. 33 are made use of in the piece of apparatus known as an **induction coil.** It is used to produce very high e.m.f.'s repeatedly, in some cases many times per second. The e.m.f.'s are so great that a current will jump across an air gap, producing a spark which may be 10 or 20 cm. long. The inner coil, sometimes called the **primary coil,**

consists of thick wire, and is wound upon a bundle of soft iron wires *AB* (Fig. 110). Upon this is wound a coil consisting of thousands of turns of fine wire, called the **secondary coil.** On starting the current in the primary coil, the magnetic lines of force produced cut all the turns of the secondary coil, and produce a high e.m.f. in each. But, as these turns are all in series, an exceedingly high e.m.f. is produced. On stopping the current

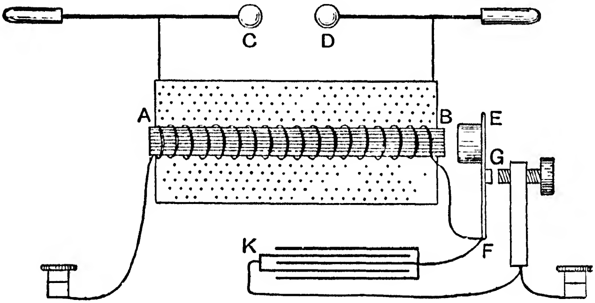

FIG. 110 —Induction coil.

the lines of force all cut again, and since the dying away of the primary current is quicker than its growth, for a reason not given here, the e.m.f. now produced is even higher than before, and causes a spark to jump across the air gap *CD*.

An automatic arrangement similar to that of the electric bell (Fig. 8) and the buzzer (Fig. 9) is used to start and stop the current repeatedly. Thus the iron core, when magnetised, attracts the piece of soft iron *E* (Fig. 110) and breaks the contact at *G* by bending the spring *EF*. When the current ceases, *E* is no longer attracted and the spring carries *E* back again and contact is again made at *G*. The **condenser** *K*, consisting of layers of tinfoil separated by paraffin paper, is placed in parallel with the

gap G, and increases the efficiency of the induction coil, but the reason for this is too complicated to give here.

The induction coil has many uses, as, for example, the production of the discharge in gases required for producing X-rays; for producing the high e.m.f. currents in wireless telegraphy; and for producing the spark required to ignite the combustible gases in the cylinder of a petrol motor or gas engine. The design of the induction coil depends upon the use to which it is to be put.

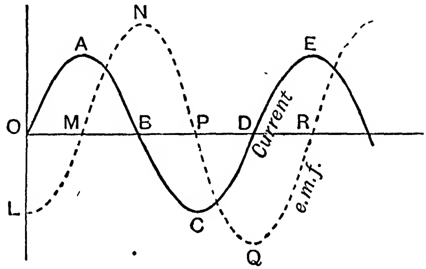

FIG. 111.—Alternating current curves.

The transformer.—Another application of the above principles, of the greatest importance, is the **alternate current transformer**. Although the transformer may be used to produce a raising of the e.m.f. or a lowering, it is generally the latter, so that its function is generally the reverse of that of the induction coil, where a few cells of e.m.f. equal to a few volts are used to produce discharges at hundreds of thousands of volts.

To understand the transformer, refer again to p. 127, where it was seen that the rotation of the coil $ABCD$ (Fig. 107) caused a current to flow first in one direction and then the other. A current of this kind is called an **alternating current**, and the method of producing alternating currents in practice is seen on p. 153. An alternating current may be represented by a curve such as $OABCDE$

(Fig. 111). The curve is supposed to give the values of the current at succeeding intervals of time. Thus, from O to A the current increases and then decreases from A to B. From B to D the current is in the reverse direction, and so on. If now the alternating current flows in the primary coil AB (Fig. 112), wound upon a circular iron core, which may with advantage be made of a bundle of soft iron wires, it will magnetise the core, first in one direction and then in the other, and the magnetic lines will pass through the secondary coil C. The e.m.f. produced in the secondary coil as these lines of force cut it, will be represented by the dotted curve in Fig. 111. It will be seen that when the primary current is changing most rapidly, as at O, B, and D, the e.m.f. in the secondary coil is greatest; while at A, C, E, etc., where the primary current is, for an instant, not changing, the e.m.f. in the secondary is zero. An actual transformer is illustrated in Fig. 113. It is generally near the truth to say that:

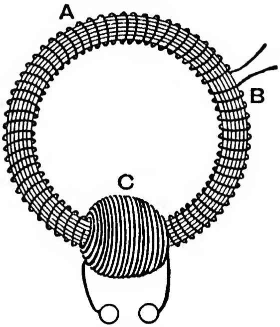

FIG. 112.—Simple transformer.

$$\frac{\text{e.m.f. in secondary}}{\text{e.m.f. in primary}} = \frac{\text{number of turns in secondary coil}}{\text{number of turns in primary coil}}.$$

Therefore to **step up** in voltage, the primary consists of few turns of thick wire, while to **step down** in voltage the reverse is the case. It is therefore possible to transform up to an e.m.f. of several thousands of volts at the generating station, and convey the current at high voltage to the place where it is to be used. As these high voltages would be dangerous in ordinary houses and factories the

e.m.f. is then transformed down to 100 or 200 volts. The advantage of this process is due to the fact that the power transmitted in watts is given by

$$\text{watts} = \text{amperes} \times \text{volts (p. 71)}.$$

Consequently the high voltage used for transmission enables small current to be used, so that comparatively thin copper mains may be employed. As copper is a very expensive metal, the conveyance of large currents over great distances is prohibitive; but the transformer has

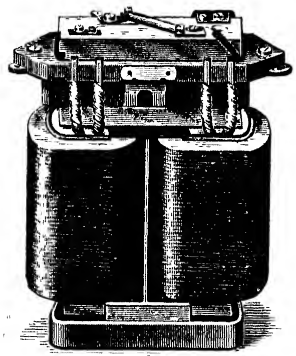

FIG. 113.—Transformer.

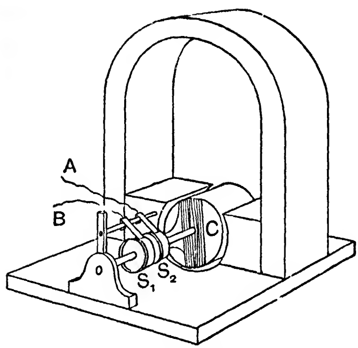

FIG. 114.—Simple alternator.

enabled the transmission to be carried out with small currents while still conveying considerable power on account of the high voltage.

Simple alternating current dynamo.—On p. 127 it was seen that when a coil rotates in a magnetic field, an alternating e.m.f. is produced in it. If, however, the coil in Fig. 107 were rotated continuously, the connecting wires would become twisted together and would soon break. To obviate this the ends of the coil are attached to two insulated brass rings S_1 and S_2 (Fig. 114), called **slip rings**. Two pieces of metal called **brushes** touch the

slip rings, one resting on each. This enables continuous rotation to take place, and, since the leads AB to the external circuit are attached to these brushes, an alternating e.m.f. will be applied to the external circuit.

The coil, of many turns of insulated wire, is wound upon the iron shuttle-shaped core C, and the axle upon which rotation occurs passes through this core. The slip rings are mounted upon the same axle and rotate with it. The coil with its iron core is called the **armature**, the whole machine being a simple form of alternating current dynamo. In this case the dynamo is shown with a permanent magnet to produce the magnetic field, but in the alternating current dynamos used in practice electro-magnets are employed.

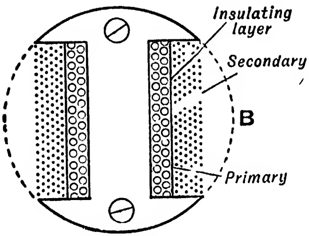

FIG. 115.—Armature of magneto.

The magneto.—In order to provide the spark necessary for igniting the combustible gases in the cylinder of a petrol motor, the **magneto** is generally employed. This is a combination of the simple dynamo and the induction coil (p. 132). A simple armature of the shuttle type (Fig. 114) is wound with two coils, the primary having few turns of thick wire, and the secondary having many turns of thin wire, just as in the induction coil. On sudden stoppage of the current in the primary, a high e.m.f. occurs in the secondary, and a spark occurs at a break which is situated in the **sparking plug** (Fig. 118) of the machine. In the magneto, the current in the primary is not produced by a battery, but is due to the rotation of the armature in the field of a permanent magnet of the type shown in Fig. 114. The core of the armature consists of H shaped soft iron sheets, made

by stamping, and bolted together with a circular brass plate at each end, shown by the dotted circle B in Fig. 115.

As the armature rotates, considerable distortion of the magnetic field occurs; for, in the position shown in Fig. 116 (a) the magnetic lines enter at one end of the coil, and in the position shown in Fig. 116 (b) they enter at the other end. Hence, during the change from one position to the other, the magnetic lines have cut the coil twice, and in doing so produce an e.m.f. This occurs twice in each revolution, and, if the primary circuit is complete, considerable current will flow in it.

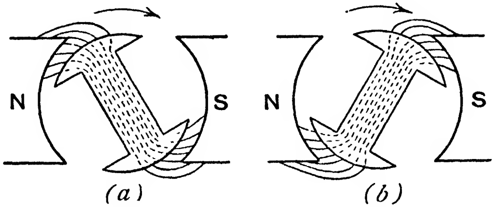

FIG. 116.—Magnetic field in armature of magneto.

By means of a rotating contact breaker, shown in Fig. 117, the primary circuit is broken, while the current is flowing in it. Hence, its rapid fall to zero, assisted by the condenser, just as in the case of the induction coil (p. 130), causes a high e.m.f. in the secondary circuit. The actual spark contact A (Fig. 117), in the primary circuit is opened by the bent lever ALB which can move about the axis L, and is held by a spring S, so that the platinum surfaces at A are in contact. The plate on which the contact and lever

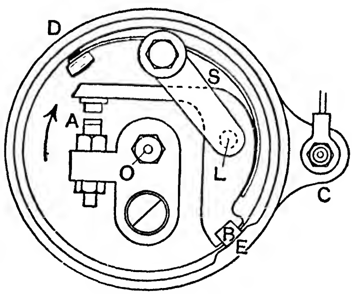

FIG. 117.—Contact breaker of magneto.

are fixed rotates with the armature of the magneto, about the axis O, and the contact is opened by the pressure of the projection E in the cylindrical cover CDE as B passes it. The position in which E is set determines

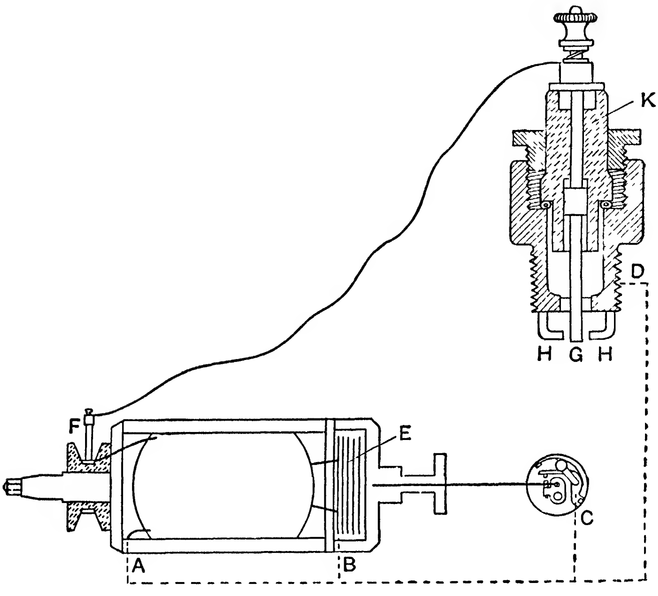

FIG. 118.—Single cylinder sparking circuit.

the moment at which the spark in the spark plug attached to the secondary occurs. CDE can slide about its axis, so that to advance the spark, that is, make it occur earlier in the working cycle of the motor, C is raised, while, to retard the spark, C is lowered.

The general scheme of connections for a single cylinder sparking circuit is given in Fig. 118. The iron-work of the motor itself is used as an earth return on both primary and secondary circuits. B, C, are connections to this

earth return in the primary circuit, and *A* and *D* in the secondary circuit. The condenser *E* is attached to the armature and rotates with it. One contact to the secondary coil is made through the insulated conducting ring and the carbon brush at *F*. This is connected by a well insulated wire to the sparking plug which is shown in Fig. 118 on a larger scale than the magneto. The single nickel rod *G* is in connection with *F* and is insulated from the body of the machine by the porcelain piece *K*, while the nickel points *H*, *H*, are in metallic connection with the body of the motor. The spark plug is screwed into the top of the cylinder, so that the spark occurs in the compressed combustible gases consisting of petrol vapour and air.

EXERCISES ON CHAPTER XI.

1. Explain how a current may be produced in a wire moving in a magnetic field, and give the rule for finding the direction of the e.m.f. produced.

2. Describe an experiment for investigating the direction of the induced e.m.f. in a coil, when the number of magnetic lines of force threaded through it varies.

3. Describe how an alternating e.m.f. may be produced by rotating a coil in a magnetic field.

4. Explain, with sketch, the action of an induction coil.

5. Give an account of the principles underlying the construction of an induction coil. Why is it that a spark is generally obtained when the primary current is broken and not when it is made.

6. What is a transformer, and what are its uses ?

7. Give a diagram of the primary current and secondary e.m.f. in a transformer.

8. What is meant by a "step up" and a "step down" transformer ? What are their uses ?

9. Describe, with sketch, some simple form of alternator.

10. Describe, with sketch, the armature of some form of magneto, with production of primary and secondary currents.

11. Describe the arrangement for interrupting the primary current of a magneto, and the manner in which the spark may be advanced or retarded.

12. Sketch the circuits of the magneto and sparking plug of a single cylinder petrol motor.

CHAPTER XII

THE DYNAMO

Commutators.—In Chapter XI. the principles upon which the dynamo is founded were given, but the actual form of the machine was not described. As the coil in Fig. 107 rotates, an alternating e.m.f. is produced in it, and by means of the slip rings (Fig. 114) the e.m.f. is enabled to produce an alternating current in the external circuit. In order to produce a current in one direction only in the external circuit, a device called a **commutator** is used. The commutator in its simplest form consists of a split ring AB (Fig. 119), to each half of which is connected one end of the rotating coil EF. Two brass conductors C and D, called **brushes**, bear upon the split ring at opposite ends of a diameter. It follows that the current will always flow in the same direction in the external circuit; because the connection between the coil and the brushes is reversed twice in each revolution, and also the direction of the e.m.f. produced in the coil is reversed twice in each revolution. This point may be seen more clearly by noticing that in Fig. 119 the side

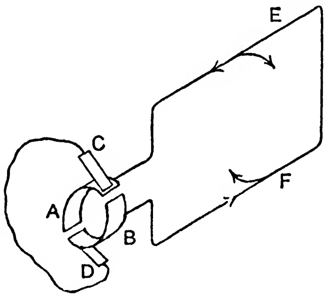

FIG. 119.—Simple commutator.

of the coil which is descending is always connected to the brush *C*, while the side of the coil which is ascending is connected to the brush *D*. Hence, the e.m.f. always acts in one direction in the external circuit.

It was seen in Fig. 111 that the alternating e.m.f. or current may be represented by a curve. Thus in Fig. 120, when the rotating coil is vertical, the e.m.f. in it is

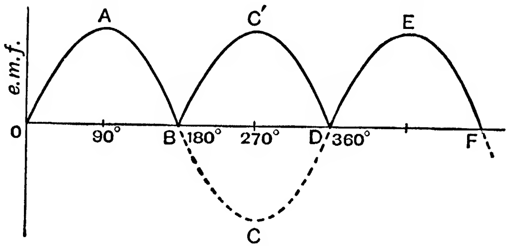

FIG. 120.—E.m.f. curve with simple commutator.

zero (p. 131), as shown at 0. When it has moved through 90°, and is horizontal, the e.m.f. is a maximum, and is shown at *A*; and, again, on movement through 180°, 270°, and 360° the e.m.f.'s. was shown at *B*, *C* and *D*. The effect of the commutator is to reverse the direction of the e.m.f. in the external circuit during half the cycle, so that the curve representing the e.m.f. in the external circuit is represented by *OABC′DE*, etc. The e.m.f. and current in the external circuit are therefore constant in direction, but they are by no means constant in value, as a glance at Fig. 120 will show.

Continuous or direct current.—A current which has constant value and flows in one direction only is called **continuous** or **direct** current (**D.C.**), in contrast with **alternating** current (**A.C.**). A perfectly constant value of the current cannot be obtained by any dynamo, but by using coils at various angles a close approximation to a constant value can be obtained.

Consider a pair of coils whose planes are at right angles to each other (Fig. 121). The ends e and h are joined to the commutator section A, and f and g are joined

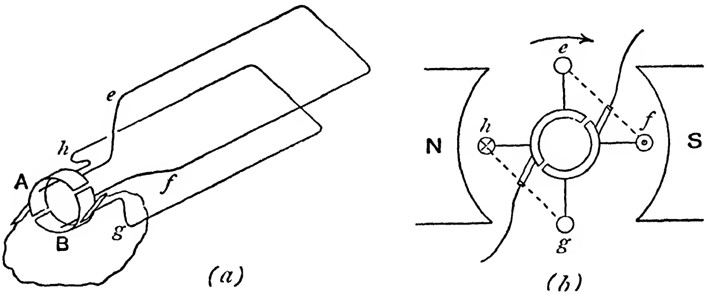

FIG. 121.

to B. The arrangement will be clearly seen from Fig. 121 (b), which is an end view of the armature and commutator with the direction of the magnetic poles shown. The connections of the coils at the back of the armature are shown in dotted lines. It will be seen that when the conductors e and g are producing zero e.m.f. the conductors h and f are producing their maximum e.m.f. On plotting the two e.m.f. curves in dotted lines in Fig. 122 and adding the values at each point of the cycle, the thick line curve is obtained. Although far from constant in value, the e.m.f. only varies between the limits OA and OB, which is not so great a variation as that for a single coil, shown in Fig. 120.

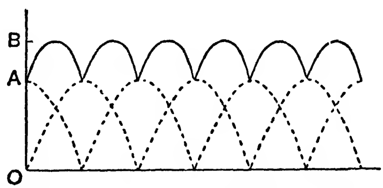

FIG. 122.—E.m.f. curve for four-conductor armature.

Drum armature.—By continuing the process of adding conductors round the circumference of the armature,

the e.m.f. and current curves may be made much smoother than that of Fig. 122. Care must be taken to have the correct number of segments in the commutator, and that the conductors are correctly connected to each other and to the commutator bars. There are many forms of armature winding, and these are in many cases of great complexity. An armature of eight conductors is shown in Fig. 123, and it will be understood that the same principle is followed when the number of conductors is very great.

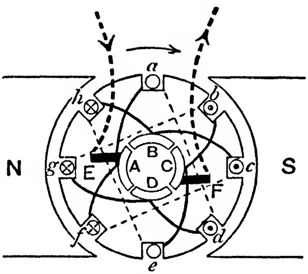

FIG. 123.—Armature with eight conductors.

The eight armature conductors lie in slots in an iron core and are shown at *abcdefgh* (Fig. 123). They are connected to the four commutator bars *ABCD* at the front of the armature, as shown by the continuous lines, and to each other at the back of the armature, as shown by the dotted lines. The conductors *b*, *c*, and *d* are descending, and the right hand rule (p. 126) shows that the e.m.f. in them is directed from back to front, which is intended to be indicated by the dot in each circle; *f*, *g*, and *h* are ascending, and the e.m.f. is from front to back, which is indicated by the tail of an arrow, represented by a cross.

On tracing out the connections it will be seen that the current from the brush *F* flows through the external circuit and enters the armature by the brush *E*. There are now two paths through the armature open to it. Therefore, part flows by the path *EAadDgbCF* and the other by the path *EAfcBheCF*.

The form of the armature consisting of many conductors

is shown in Fig. 124. From its shape it is called a **drum armature**. In a case such as this, the iron core is built up of stampings from iron sheet, with the slots for the armature conductors round the circumference. Precautions have to be taken to insulate the conductors and commutator bars from each other and from the rest of the machine.

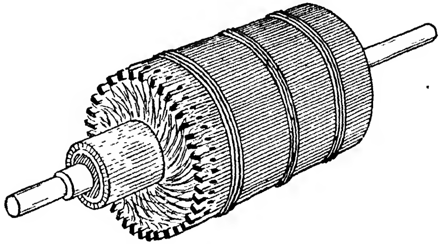

FIG. 124.—Drum armature.

Field magnets.—In all but the smallest dynamos, the magnetic field is produced by an electro-magnet. There are many different forms of electro-magnet used, and the current required to excite the magnet may be derived from a separate source, such as a battery, in which case the dynamo is said to be **separately excited**, or the current for the electro-magnet may be produced by the dynamo

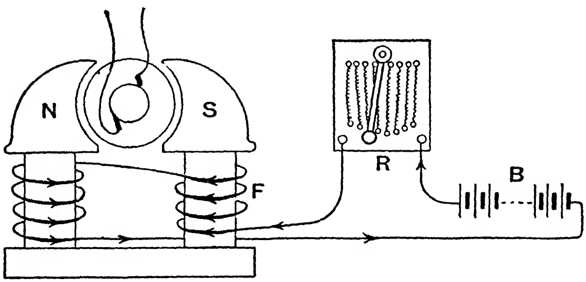

FIG. 125.—Separately excited field magnet.

itself, in which the dynamo is said to be **self excited**. Separate excitation is only used in the large dynamos employed in central supply stations, where it is necessary

to regulate the e.m.f. of the supply by hand. Should the e.m.f. of supply drop, the switch-board attendant cuts out resistance from the battery and field magnet circuit, which increases the field current, and therefore the magnetic field of the supply dynamo. The reverse causes a drop in e.m.f. A suitable arrangement is shown in Fig. 125, where *R* is a rheostat, *B* a secondary battery, and *F* the field coils of the dynamo. In many cases a smaller dynamo replaces the battery *B*.

Series wound field magnets.—In most dynamos the current for exciting the field magnets is derived from the machine itself. But there are several ways of doing this. If the current produced by the armature, and flowing in the external circuit, also flows through the field coils, they are in series with the armature and external circuit as in Fig. 126. This is called **series** winding.

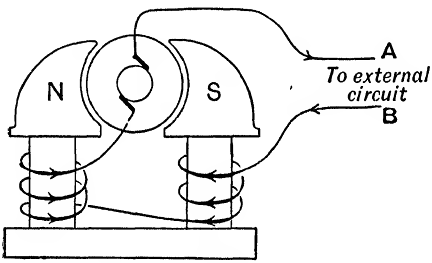

FIG. 126.—Series wound dynamo.

It is applicable to dynamos for incandescent lamps, but not for the charging of accumulators. For, let the lead *A* (Fig. 126) be connected to the positive end of the secondary battery. Before completing the circuit there is no current in the field coils, and no magnetic field, except that due to any small residual magnetisation acquired in the previous running of the machine. The battery has, however, its full e.m.f. or nearly so, and will therefore send a current from *A* through the armature and field coils to *B*, which will give the wrong magnetisation to the field magnets and reverse the e.m.f. of the dynamo. Thus, the e.m.f. due to the dynamo will send a current in the wrong direc-

tion through the cells, causing further discharge instead of the required charging of the battery.

It should also be noticed that the series coils of a dynamo are of thick copper and are few in number, since they must have low resistance, on account of their carrying the whole current produced by the machine.

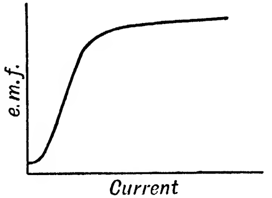

FIG. 127.—Characteristic of series dynamo.

Characteristics of a dynamo.—If a series dynamo be run at constant speed, and measurements of the e.m.f., produced with different currents flowing, be made and plotted in the form of a graph, the curve obtained is called the **characteristic** of the dynamo. Such a characteristic is given in Fig. 127. It will be seen that as the current increases, the e.m.f. increases, which would be expected, because the increasing current produces greater magnetic field, and more magnetic lines of force are cut by each conductor in the armature in every revolution.

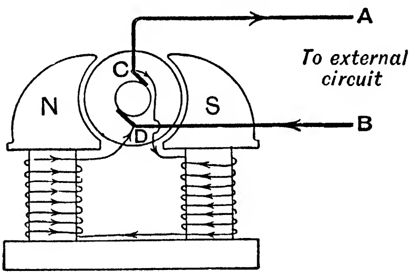

FIG. 128.—Shunt wound dynamo.

Shunt wound field magnets.—In contrast to the series arrangement there is the **shunt winding** illustrated in Fig. 128. The external circuit and the field coils are in **parallel**, or the field coils are placed as a **shunt** across the external circuit. The current in the armature therefore divides on reaching the brush *C*, part going to the external circuit and part to the field coils. These two parts of the current unite again at the brush *D*.

The shunt wound dynamo may be used for most purposes, in particular for charging accumulators. For it will be seen that on connecting the positive pole of the battery to A and the negative pole to B, a current will be caused to flow in the shunt coils in the direction which will give the correct polarity of the pole pieces, and the full e.m.f. for **charging** the battery will be produced, provided that the armature is running at its proper speed.

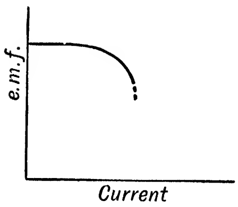

FIG. 129.—Characteristic of shunt dynamo.

The characteristic of a shunt dynamo is shown in Fig. 129. It will be seen that with increasing current in the external circuit, the e.m.f. of the machine drops. The reason for this is that the current increases because the external resistance decreases. Thus, a smaller current will flow in the shunt circuit, and the magnetisation therefore falls off.

Since the whole e.m.f. of the armature is applied directly to the ends of the shunt coil, this coil must have many turns of fairly fine wire, so that its resistance is sufficient to prevent an excessively great current flowing in it.

Compound wound dynamo.—It has been seen that in the case of the series wound dynamo, the e.m.f. rises with increasing current, while in the shunt machine the e.m.f. falls off. It can therefore be understood that, by an appropriate combination of the two methods, a dynamo may be produced in which the e.m.f. is the same for all external currents. Such an arrangement is called **compound winding**, and is illustrated in Fig. 130. It may be looked upon as a shunt winding with a few series turns wound over them, so that the drop in magnetisation, which

occurs with shunt coil alone when the load is increased, is compensated by the increase in magnetisation due to the extra current in the series turns.

On referring to Figs. 127 and 129 it will be seen that the characteristic curve of a correctly compounded dynamo is a horizontal straight line.

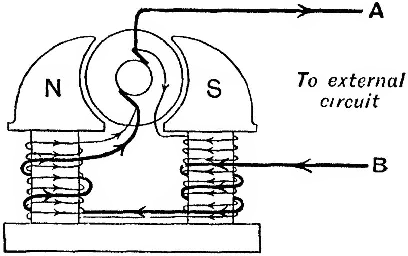

FIG. 130.—Compound wound dynamo.

Brushes and brush holders. — There are many varieties, but only two types of brush are used in connection with dynamos and motors, namely, the **metal brush** and the **carbon brush.**

The metal brush consists of thin sheet, wire or gauze of brass or copper, compressed into rectangular form. One edge bears against the commutator, and is shaped

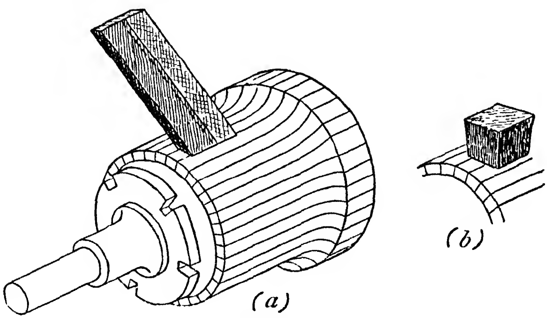

Fig. 131.

at the end accordingly. The usual shape of a gauze brush is given in Fig. 131 (*a*), and of a carbon brush in Fig. 131 (*b*). The latter is made of compressed graphite, and rests perpendicularly on the commutator. It has the

advantage over the gauze brush, that, on account of being set perpendicularly to the surface of the commutator, the brush does not require resetting if the direction of rotation is reversed. This is of particular importance in the case of electro-motors.

The brushes are carried in **brush-holders**, which, while holding the brushes firmly on to the commutator, enables them to be moved around the axis of rotation of the

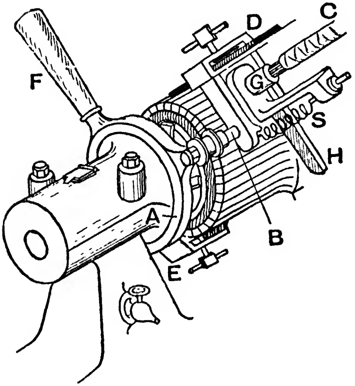

FIG. 132.—Commutator and brush holders.

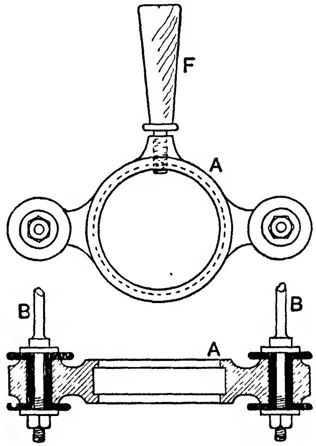

FIG. 133.—Plan and elevation of carrier holder.

armature. A ring A (Fig. 132) carries the horizontal pins B, only one of which can be seen, on which the actual holders D and E are fixed. The brushes are clamped into them, and the springs, one of which is shown at S, keep the brushes in contact with the armature with sufficient force to prevent them jumping. The insulating handle F screws into the ring A, and, passing through, bears upon the support, and so fixes the position of A and of the points of contact of the brushes on the commutator. On turning F to loosen it the brushes may

be rotated into the position in which there is least sparking between the brushes and commutator. On finding this position the brushes are fixed by screwing up *F*. The cable is soldered into the thimble *G*. *H* is an insulating lever by means of which the actual brush holder *D* can be raised so that the brush is just clear of the commutator. The holder carrier is seen in elevation and in sectional plan in Fig. 133, which will make its action clearer. A suitable form of brush holder for carbon brushes is given in Fig. 134.

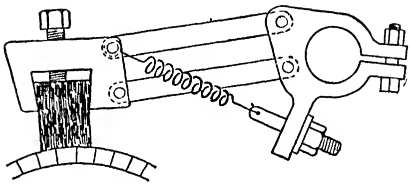

FIG. 134.—Carbon brush holder.

Sparking of the brushes.—Whenever a spark occurs between the brush and commutator, some of the metal of both is worn away, by being volatilised, as a short-lived arc is formed (p. 87). The wearing away of the brush does not matter much, but the wearing of the commutator occurs at the edge of the bars and soon wears away the smooth commutator surface, which rapidly becomes roughened and pitted. This roughening again increases the sparking, and if allowed to proceed would soon spoil the commutator. Hence, sparking is an evil which must be prevented.

The reason for sparking may be seen on examining Figs. 121 (*b*) and 123. In the first place, the thickness of the brush must be sufficient to bridge over the insulation between two commutator bars, so that the external circuit is never interrupted. It follows, therefore, that where this bridging across occurs, some circuit in the armature is shorted. In Fig. 121 (*b*) the circuit *ef* is just about to be shorted by the brush *B*, and in Fig. 123 the circuit *DgbC* has just been short circuited by the brush

F. If there is any e.m.f. in a circuit when it is shorted, a very great current will be produced in it, and as the commutator travels forwards and the short circuit is broken a big flash will occur (p. 87).

Hence, to prevent sparking, it must be so arranged that while any given circuit is shorted, there is no e.m.f. in it, that is, it is not cutting across magnetic lines of force.

With a pair of pole pieces as in Fig. 135 (*a*), a single coil would have no e.m.f. in it when vertical, as in Fig. 120,

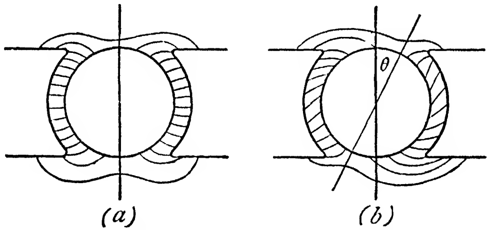

FIG. 135.—Magnet field round the armature.

and for sparkless running the brushes must short circuit such a coil when in this position. But when the armature consists of conductors all round the armature, as in Fig. 123, it will be seen that the currents flow in one direction in *b*, *c* and *d*, and in the other in *f*, *g* and *h*, and this causes magnetisation of the iron core in a direction at right angles to that of the original field. The effect of the superposition of this magnetic field upon the original field is to distort the field from the shape shown in Fig. 135 (*a*) to that of Fig. 135 (*b*). Thus, the brushes must be moved forward through the angle θ to maintain sparkless running. This angle is called the **lead of the brushes**.

The iron filing method of obtaining a magnetic field (p. 24) has been used to trace these fields. In Fig. 136 the field magnet alone is excited. In Fig. 137 there is current in the armature only, and in Fig. 138 both fields

are present. It will be seen that the resultant field is of the form given in Fig. 135 (*b*). The correct position for

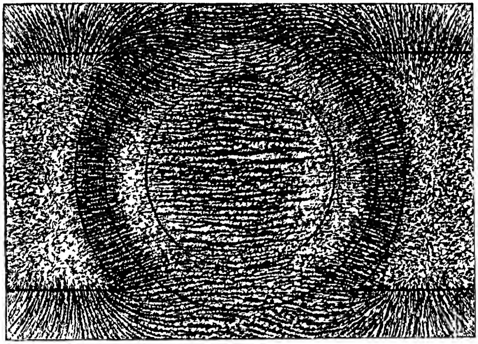

FIG. 136.—Field due to field magnets.

sparkless running is found by trial, but if there is any considerable alteration in the current flowing in the armature, the lead of the brushes must be altered until the amount of sparking at the brushes is extremely small.

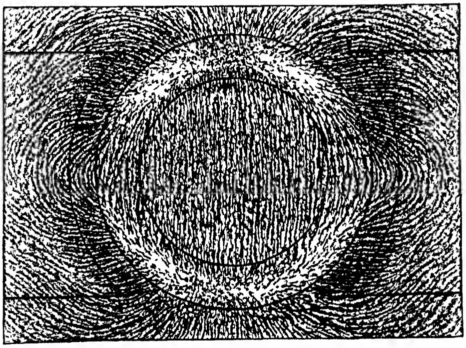

FIG. 137.—Field due to armature.

General arrangement of the dynamo.—The general arrangement of a dynamo may be seen in Fig. 139. The iron framework which forms part of the field magnet

core also carries the bearings for the armature shaft. The brush holders, with their movable carrier, can also be

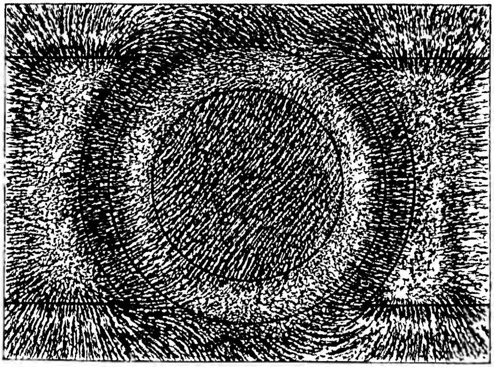

FIG. 138.—Field due to magnets and armature together.

seen, as well as the thick leads from the brushes to the external circuit. The actual machine shown in Fig. 139 is a combination of electro-motor and dynamo, in which

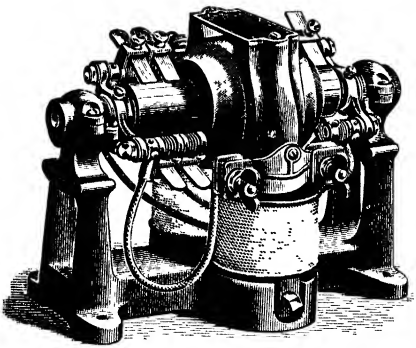

FIG. 139.—D.C. dynamo.

it is necessary to transform continuous current at high voltage to continuous current at low voltage. The high

voltage current is supplied to the right hand commutator, as seen in Fig. 139, and the low voltage current is taken from the left hand commutator. The same field magnet and armature coil serves for both circuits.

Alternators.—The simple alternator shown in Fig. 114 is of no use for practical purposes, since the speed of revolution of the armature would have to be prohibitively great in order to obtain the e.m.f. and number of alternations per second required in practice.

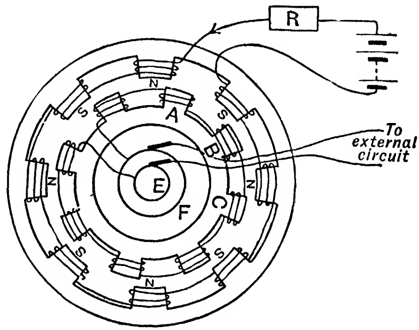

FIG. 140.—Eight-pole alternator.

The rotating part, usually called the **rotor**, generally plays the part of the armature in the direct current dynamo; and the fixed part, called the **stator**, generally acts as the field coils, but these conditions are sometimes reversed.

The number of magnetic poles of the field magnet may be considerable. Eight poles only are shown in Fig. 140 for the sake of simplicity, but the number is frequently 32 or 64. The turns *A*, *B*, *C*, etc., are in series, and are oppositely wound. Hence, coil *A* is passing a *N* pole at the same time that *B* is passing a *S* pole; the e.m.f.'s produced all act the same way round the rotor circuit. At some point the rotor circuit is broken, and the ends connected to the slip rings *E* and *F*, which are actually of the same size and are placed side by side on the axle. The number of complete alternations of e.m.f. per revolution of the rotor is half the number of poles in the stator, or equal to the number of pairs of poles.

By means of the rheostat *R* the current in the stator coils can be varied and the e.m.f. produced by the alternator regulated.

The question of the production and use of alternating currents is highly complex and cannot be considered further here.

EXERCISES ON CHAPTER XII.

1. Describe how the alternating current produced by a coil rotating in a magnetic field can be converted into a current in one direction.

2. Give a sketch of the commutator and connections for an eight bar drum armature.

3. What are the different modes of excitation of the field magnets of a direct current dynamo ?

4. What are the relative advantages of a series wound and a shunt wound dynamo ?

5. Give an account of the method of winding the field coils of a direct current dynamo by compound winding, in order to produce a machine giving constant e.m.f. for all currents.

6. What is the 'characteristic' of a dynamo, and what are its uses ?

7. Describe, with sketches, some form of brushes and brush holder for a dynamo.

8. What is the cause of sparking at the brushes of a dynamo ? How may sparking be remedied ?

9. What are the principal points of an alternator ? How may the number of alternations per cycle be found ?

10. How may the e.m.f. produced by an alternator be regulated ?

CHAPTER XIII

ELECTRO-MOTORS

Force on current in magnetic field.—In Chapter V. the force on a conductor carrying a current when situated in a magnetic field was studied, and on p. 40 the rule for the direction of the force in relation to the current and magnetic field was given. This force lies at the basis of all electro-motors, and it must now be studied more carefully.

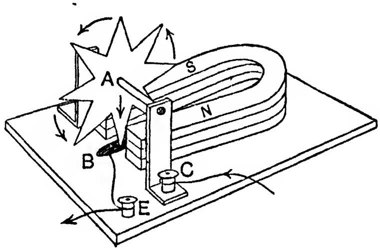

Fig. 141.—Faraday disc.

Faraday disc.—A sheet copper or brass disc, indented to form a star shape, with an axle passing through it, is mounted between brass supports, and the lower points dip into a pool of mercury *B* (Fig. 141). It follows that, on connecting the terminals *C* and *E* to a battery, a current may be made to flow in the disc from the axle *A* to the mercury *B*. The horse-shoe magnet *NS* is placed so that its field passes through the disc from front to back, and the current from *A* to the mercury is situated in this magnetic field and at right angles to it. There will consequently be a force tending to rotate the disc, and from the *left hand rule* given on p. 40 it follows that the disc should turn in an anti-clockwise direction,

as seen in the figure. This will be found to be the case.

Force between parallel currents.—Since a current produces a magnetic field, a second current in its neighbourhood will experience a force.

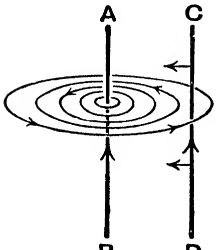

FIG. 142.—Force between currents.

Consider a wire AB (Fig. 142) in which the current is flowing from B to A. The magnetic lines of force are circles whose direction is shown by arrows. A second wire CD, parallel to AB, has a current flowing in it from D to C. On applying the left hand rule (p. 40) it will be seen that CD experiences a force driving it towards A. Similarly AB is driven towards CD. Also, if **one of the currents** be reversed, the wires are driven apart. The following rule can then be deduced :

parallel currents in the same direction attract each other, parallel currents in opposite directions repel each other.

Jumping spiral.—Let a spiral of wire AB (Fig. 143) be hung from a metal support CD, with the lower end B just touching a pool of mercury, connected to the terminal E. On connecting E and D to a battery, a current flows in the spiral. But the current in each turn of the spiral is near the current in the neighbouring turns, and the currents are **in the same direction**. Therefore, each turn of the spiral attracts the neighbouring turns and the

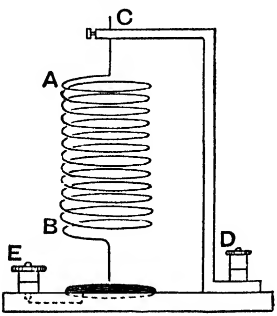

FIG. 143.—Jumping spiral.

spiral contracts, the contact at B being broken, with formation of a spark. Immediately the current ceases to flow the attractions between the turns cease, and the spiral falls to its original position, making contact again, with repetition of the process. This arrangement has been called the **jumping spiral.**

Dynamo used as a motor.—On referring to Fig. 123, let us see what the effect will be of applying some source of e.m.f. to the brushes, so that a current is caused to flow in the armature, independently of any rotation that there may be. The current in b, c and d (Fig. 144) will now be from back to front, and in f, g and h from front to back. On applying the left hand rule, it will be seen that b, c and d experience an **upward force**, and f, g and h **downward force**. These forces will cause rotation of the armature in the opposite direction to that in which it was previously driven by mechanical means. This is only one example of the general rule that **if a current be supplied by external means to a dynamo the machine will now run as a motor.**

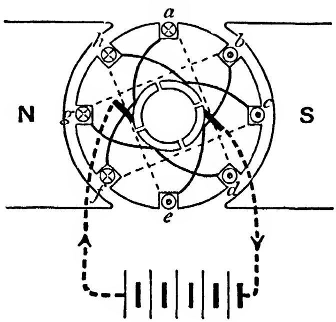

FIG. 144.—Dynamo used as a motor.

With the same direction of magnetic field and the same direction of current in the armature conductors, the **rotation is in the opposite direction** when running as a motor to that in which, as a dynamo, it was driven. This rule applies to all **direct current** dynamos. In the case of **alternators** the current supplied to the armature must be **similar in every way** to the current produced when running as a dynamo. That is, the current must be alternating,

and its direction at each position of the armature must be correct.

Thus, there is no essential difference between a direct current dynamo and a direct current motor, but differences in design are employed in accordance with the use to which the machine is to be put.

Series wound motor.—Where small motors are to be driven by a few accumulators, the field magnets of the motor are usually placed **in series** with the armature. Such motors are, however, little more than toys, and an armature of the **shuttle** type (Fig. 114) is used. In Fig. 145 is shown a simple series wound motor which can be run by two or three accumulators. The brushes are carried by the insulating arm AA, which can be rotated until the position of the brushes is correct, in which case the running is sparkless.

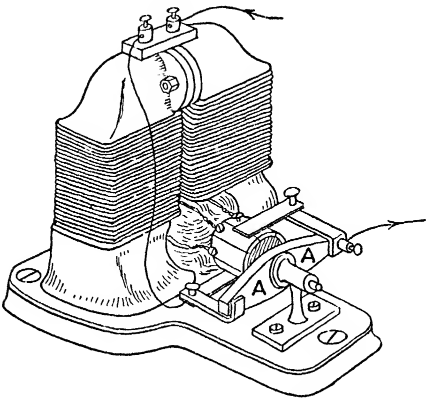

FIG. 145.—Series motor.

In the case of larger machinery it should be noticed that on first switching on the current, the field coils, being of low resistance and in series with armature, carry very great current (p. 145), and this gives a large force on the armature conductors. Thus, series motors are used for trams and trains where the largest pull is required at the start.

Shunt wound motor.—Motors not required for traction are often of the **shunt type**, and may also be **compound**

wound; but in the latter case the importance of the shunt coils predominates over that of the series coils. When the voltage of supply is high, usually 100 to 500 volts, it is essential that the field coils should have considerable resistance, or the current in them would be so great that the insulation would quickly be destroyed. A shunt motor runs at nearly constant speed under all loads. On referring to Fig. 146 it will be seen that, with the connections as shown, the direction of rotation will be that indicated by the arrows *C* and *D*. If now the e.m.f. of supply be reversed in direction, the current in each armature conductor will be reversed. But the polarity of the field magnet is also reversed, so that the **direction of rotation will be the same as before.** Hence, in order to reverse the direction of rotation of a motor, it will not suffice to reverse the direction of the applied current, or e.m.f. In order to cause reversal of the direction of rotation it is necessary to reverse either the current in the armature or the current in the field magnet coils, **but not both.** This may be accomplished by the use of a reversing switch in one of these circuits, usually the armature circuit.

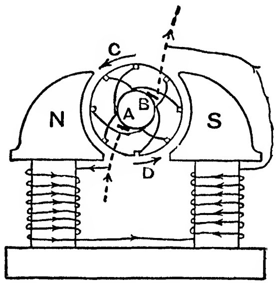

FIG. 146.—Shunt wound motor.

Back e.m.f. in armature.—The resistance of the armature is always small, and it might therefore appear at first sight that the current in it, when the high voltage is applied, would be excessive. This is certainly the case when the armature is at rest. But it must be noticed that, when the armature is rotating, each conductor is cutting across magnetic lines of force, and therefore an

e.m.f. is produced in it, proportional in value to the number of lines of force cut per second. This law is universally true, and is not at all affected by the fact that the motion is due to this same magnetic field.

In order to find the direction of this e.m.f. refer to Fig. 144. On applying the right hand law (p. 126) to the conductors *b*, *c*, and *d*, it will be seen that the e.m.f. due to cutting magnetic lines of force is from front to back, and in *f*, *g* and *h* from back to front; that is, it is the opposite direction to the applied e.m.f. and tends to reduce the current in the armature. Such a one is called a **back e.m.f.**

On first switching on the current to a motor, the armature is at rest and there is no back e.m.f. The current will therefore be determined in value by the resistance of the armature only, and, if not prevented, it would therefore be very great. This is an advantage, provided that the current is not great enough to cause injury, because it gives the great force on each conductor of the armature which is required to start it under load. As the armature picks up speed, the back e.m.f. increases, and the current is consequently diminished. The current for continuous running must not be great enough to injure the insulation of the armature.

Starting resistances.—In large motors the current at the start would be far too great, unless some resistance were placed in the armature circuit. This resistance may be cut out step by step until the full speed is attained and the back e.m.f. is sufficient to keep the current in the armature down to a safe value. Such resistances, of which there are many designs, are called **starting resistances.** One form of starting resistance for a shunt motor is shown in Fig. 147. When the motor is not run-

ning, the contact arm *AO* is pulled back by the spring *S*, and both armature and field circuits are incomplete. When the arm is raised it first makes contact with *P*, and both field and armature circuits are completed, but the armature current is kept to a reasonable value by the resistances *R*, *R*. When the speed of the armature has become sufficient, *AO* is moved forward to cut out one resistance coil. This process is continued until all the coils are cut out, at which moment the face *A* of the iron contact arm comes in contact with the poles of the electro-magnet *M*, which is magnetised by the current also flowing in the field coils of the motor, and, by its pull on *A*, holds the contact arm. Consequently, should the field current fail for any reason, the magnet *M* releases the contact arm *AO*, which is pulled back and cuts off the motor from the mains. This device avoids the burning out of the armature consequent upon the disappearance of the back e.m.f. due to the failure of the magnetic field.

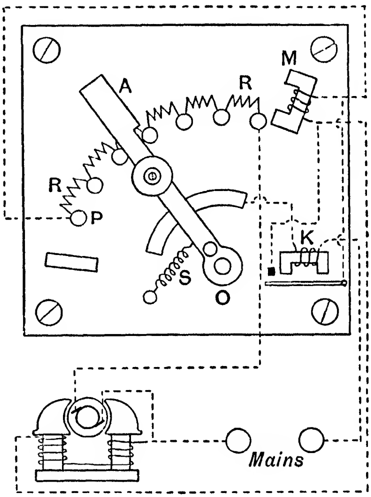

FIG. 147.—Starting resistance for motor.

Another safety device consists of an electro-magnet *K* which attracts upwards an iron bar and short circuits *M*, with the result that *A* is also in this case released. The electro-magnet *K* is actuated by the armature current, so that if this should become too great, owing to

the overloading of the motor, the supply current is automatically cut off.

Lag of the brushes.—It was seen on p. 150 that the current in the armature produces a magnetic field which distorts the field due to the field magnets, and that, owing to this, the brushes had to be given a "lead," that is, displaced forwards, in order to obtain sparkless running. Also, on reference to p. 159, it will be seen that if the direction of running and the direction of magnetic field due to the field magnets are the same in the motor as in the dynamo, then the current in the armature bars must be the reverse in direction. It may therefore be concluded that the disturbance of the magnetic field in the case of a motor will be the reverse of that for a dynamo, and since the latter requires a "lead" for sparkless running, the brushes of a motor must be given a **lag.** That is, if the brushes are set in a position of symmetry with respect to the magnetic field before the current is switched on, then the brushes must be moved through an angle in the opposite direction to that in which the armature is running in order to have minimum sparking. The correct position for running is found by trial as in the case of the dynamo.

Motor used as a brake.—On electric trams and trains, the motors which produce the driving power also act as brakes. To accomplish this, the supply current is cut off from them, and a resistance which can be reduced by steps is connected across their ends. The momentum of the tram thus drives the motors as dynamos, and the energy of the tram is so used up.

In Fig. 148 the circuits of a series motor used for traction are represented. The leads from the various parts are taken to a complicated switch S which is placed at the front of the vehicle. M_1 and M_2 represent the

mains. The current goes from M_1 through the armature, then to the field coils and out to the main M_2 when the machine is acting as a motor and is producing mechanical power, as shown in Fig. 148 (*a*). The resistance R is in this case out of the circuit. Rotation is taking place in the direction of the arrow A, and the small arrows

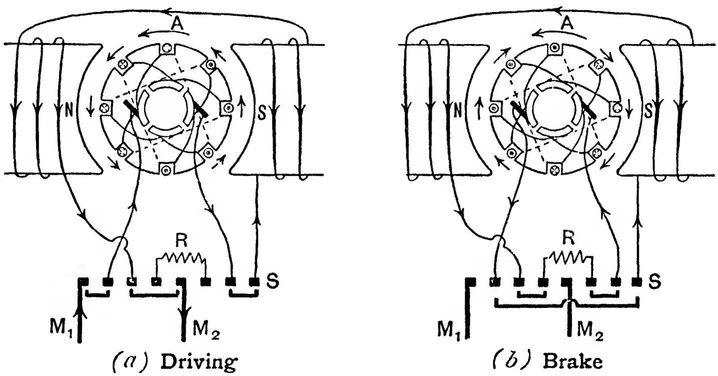

FIG. 148.—Motor used as a brake

show the direction of the force on the separate armature conductors.

If now the connections are removed to the alternative position, shown at S in Fig. 148 (*b*), it will be seen that the mains are cut off, and the resistance R placed in series with the armature and field coils. Owing to the momentum of the tram or train, the armature, which is geared to the wheels, is still driven in the direction of the arrow A, and the machine is driven as a dynamo. On tracing out the connections it will be seen that the current is produced as shown in Fig. 148 (*b*), and on applying the left hand rule (p. 40) it follows that the force on each armature conductor is in the direction of the small arrows. This is in the opposite direction to that of rotation, and it

follows that the dynamo is acting as a brake, and will bring the tram to rest. The resistance R is in sections, which may be cut out one at a time as the speed is reduced. The resistance is necessary, since the current would be too great, and would probably cause burning of the armature insulation. if the machine were merely short circuited. This case may be contrasted with that of the resistance used when a motor is started (p. 160).

The driver's switch is further complicated by the fact that the motors are supplied in series, two or four in each series, when the current is switched on. In this way the current is kept down to a reasonable value at the start, without the use of separate starting resistances. As the speed of the motor increases, the motors, if four in series, are switched over to an arrangement of two series in parallel having two motors in each series. Again, on reaching the greatest speed for this arrangement, the motor connections are altered so that the motors are all in parallel. Thus no motor is placed directly across the mains until the back e.m.f. is sufficient to prevent dangerously great current. The complication of the control switch for such an arrangement is too great for it to be described here.

Such a brake as is described above has many advantages over a friction brake. It can be applied and its pull varied without any shock to the train, but it should be noticed that it cannot hold the train at rest on an incline, because, when the armature is at rest, the braking effect ceases. It follows that it cannot be employed alone, but must always be accompanied by a friction brake for holding the train at rest.

Supply meters.—Most of the electric power produced is supplied to consumers for the purpose of lighting, and for motors for driving machinery. It is necessary, there-

fore, that the power supplied should be measured and recorded, so that the proper charge can be made. The unit of work used for such purposes is called the **kilowatt-hour**, and is the amount of energy given to a circuit when a rate of working of one kilowatt or 1000 watts is continued for one hour. It is the **Board of Trade Unit.**

On referring to the electro-motor (Fig. 144), it will be seen that the force on each conductor of the armature depends upon the current in it, and upon the strength of the magnetic field in which it is situated. The strength of the magnetic field depends upon the current in the field coils, and, if the field were produced without the intervention of any iron core, the strength of the magnetic field would be proportional to the current producing it. This principle is employed in some of the most efficient supply meters, one of which is illustrated in Fig. 149. The meter is essentially an electro-motor, the speed of which depends upon the power supplied to the installation. The current from the mains passes through the installation where the power is being used, and through the coils *BC*, consisting of thick wire. The path *ABCD* is through the meter, and the coils produce a fairly strong magnetic field. They are known as the **series coils** of the meter. The **shunt coils** constitute the armature

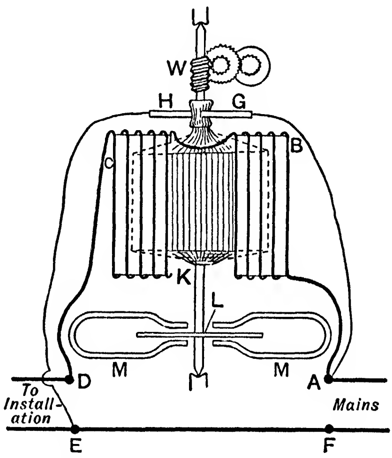

FIG. 149.—Elihu Thomson supply meter.

K, and consist of many turns of fine wire. This armature is supplied by current which enters at A, then goes to the brush G to the commutator, then through the armature and out by way of the brush H, to the mains by E and F. The current in the armature is therefore proportional to the p.d. betweed the mains, and the magnetic field, due to the series coils, is proportional to the current in the installation. It follows that the forces on the armature conductors which cause rotation are proportional to the product of the p.d. and the current, that is, to the watts being used in the installation. Thus, the greater the power being used, the greater will be the speed of rotation of the armature. In order to render the instrument useful, a suitable brake must be supplied, so that the speed of rotation of the armature shall not be excessive. This brake takes the form of a copper disc L, which is attached to the axle of the armature and passes between the poles of permanent magnets M, M. As it passes through the magnetic field, currents are produced in it (p. 125), and these currents are in such a direction that they produce a magnetic field which attracts the poles of MM as the disc leaves them, and hence causes a check upon the rotation of the disc.

It only remains to provide a suitable counter of the revolutions. The worm W on the axle gears with a toothed wheel, which in its turn gears with another wheel, and so on, appropriate pointers and scales being provided. When suitably designed, the lowest pointer and scale reads Board of Trade Units, the next scale 10's of units, the next 100's and so on.

EXERCISES ON CHAPTER XIII.

1. Describe some simple experiment for exhibiting the force on a current in a magnetic field.

2. State and explain the forces existing between two parallel wires which are carrying electric currents.

3. Explain, with sketch, why a dynamo supplied with current will run as a motor.

4. What are the relative advantages of a series wound, and a shunt wound motor.

5. Sketch the connections of a shunt wound motor, giving the direction of the current in the armature and the field windings, and pointing out the direction of rotation.

6. Why is there a back e.m.f. in the armature of a motor ?

7. State the reason for a starting resistance for a motor, and sketch some form of the apparatus.

8. What are the conditions for sparkless running of a motor ?

9. What form of electro-motor is used for electric traction ? How may it be employed as a brake ?

10. What is the Board of Trade unit of electric energy ? Describe some form of electric meter.

CHAPTER XIV

TELEPHONES

Sound waves.—When an explosion or sudden compression of the air at any place occurs, the air does not remain compressed, but rebounds, just as a released spring would do. In rebounding it compresses the air in front of it, and so on. Thus, a state of compression travels forwards through the air, and is called a **sound wave.** Of course a rarefaction, or partial vacuum, may be transmitted in exactly the same way as a compression, as may be seen on suddenly drawing a cork from a bottle.

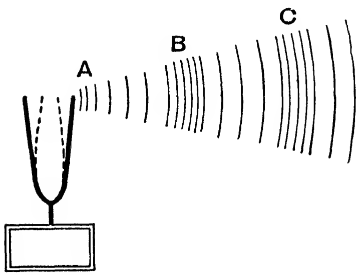

FIG. 150.—Compression waves produced by a tuning fork.

Nearly all sources of sound are **vibrating bodies,** which give trains of compressions and rarefactions. Thus, the tuning fork in Fig. 150 is supposed to be vibrating. The prong *A* is moving backwards and forwards. When it moves forwards it compresses the air in front of it; when it moves backwards it rarifies the air. Thus, parts of the sound waves, or states of compression, as indicated by *ABC*, Fig. 150, travel outwards.

Other sounding bodies, such as the vocal organs, or

musical instruments, give out sound waves in an exactly similar manner, but generally they are more complicated than the waves from a tuning fork, and each form of wave is characteristic of the sound produced.

When these sound waves fall on the drum of the ear, the drum is driven in by the compressions, and pulled outwards by the rarefactions, and so copies the motion of the original sounding body. The method by which the brain becomes conscious of the motions of the drum of the ear will not be considered here.

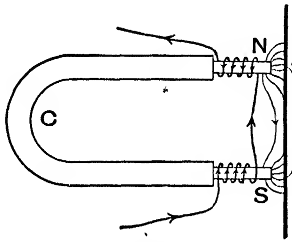

FIG. 151.—Principle of the Bell telephone.

Bell telephone.—The earliest successful form of electric telephone was due to Graham Bell, and consisted of a **transmitter** for converting sound waves into variations of strength of an electric current, and a **receiver** for converting variations in strength of the electric current into sound waves. In the Bell type, the transmitter and receiver are of the same form, and in modern telephony the Bell receiver is still used, but the transmitter has been changed considerably.

In the Bell transmitter, a thin iron sheet AB (Fig. 151) is placed very near to the poles N, S of a magnet. The permanent magnet C may be of the horseshoe type, as shown in the figure, or it may be a straight bar, in which case only one pole, either N or S, is situated near the thin sheet of iron. The pole pieces are of soft iron and are wound with coils as shown, but in the straight magnet type only one pole piece is used.

The form of the lines of force is indicated in Fig. 151, many of them passing through the iron sheet or diaphragm AB. If the diaphragm moves towards the magnetic

poles, the distribution of the magnetic lines will be changed and their number will be increased. As the diaphragm moves away, the number of lines of force present will be diminished. Each change in the number of lines of force linked with the coils surrounding the pole pieces produces an e.m.f. in the coils (p. 128) and will thus cause a variation in the current in the coils. As the sound waves produced by the speaker fall on the diaphragm, the compressions drive it in and the rarefactions draw it out, so that the air waves cause variations in the current in the coils. This arrangement therefore acts as a **transmitter**.

An exactly similar arrangement at the other end of the line acts as a **receiver**, for, the transmitter and receiver being in series, the variations in current produced by the transmitter also occur in the coils of the receiver. When the current increases, the magnetic poles increase in strength and the iron diaphragm is pulled in, and when the current decreases, the pull on the diaphragm is lessened and its own elasticity pulls it out. Hence it vibrates with the same rapidity as the diaphragm of the transmitter, and, exactly like the tuning-fork of Fig. 150, produces air waves, which in this case correspond to the waves which produced the motion of the diaphragm of the transmitter.

The microphone.—It has long been known that the point of contact of two conductors is very sensitive to variations in pressure, that is, the electrical resistance of the contact changes considerably with any slight variation in the pressure between the surfaces. This is particuarly the case with carbon, and on this account the variation of resistance of a carbon contact has been used in the construction of sensitive transmitters. If a carbon rod *AB* (Fig. 152), pointed at the ends, rests

between two carbon blocks C and D, and be made part of an electric circuit containing a battery E and telephone receiver R, then any mechanical disturbance of AB causes a variation in the resistances of the carbon contacts at A and B, and the variations in the current so produced will cause a sound to be heard in the telephone receiver R. Thus, if a watch be placed upon C or D, the ticking can be heard clearly in the telephone receiver, although this may be so far away that it is quite out of the question to hear the ticking by means of the direct air waves.

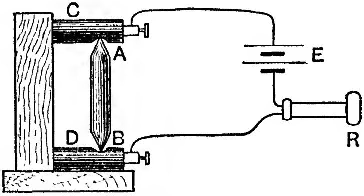

FIG. 152.—Carbon microphone.

Telephone transmitter.—In order to apply the principle of the carbon microphone, some form of carbon contact placed in the electric circuit must be acted upon by the sound waves, so that a variable pressure is produced at the contacts. In the modern form of transmitter, a thin carbon diaphragm A (Fig. 153), is situated at a short distance from a carbon block B, electrical contact between the two being made by a number of carbon pellets or granules seen at C. The diaphragm is carried in a metal capsule D and the block B is also carried by the capsule, but is insulated from it by the ring of ebonite E and the mica washer F.

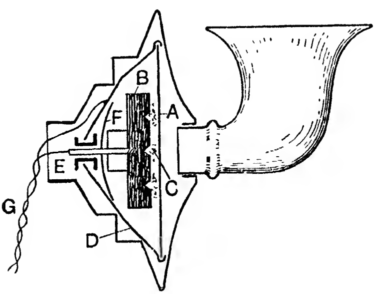

FIG. 153.—Microphone transmitter.

When the sound waves meet the diaphragm A they

set this in vibration, and so cause changes in the resistance between the diaphragm and the carbon block *B* by disturbing the contacts between these and the carbon granules touching them. Hence, the necessary variations of current are transmitted to the line, as described on p. 171.

Telephone receiver.—A modern form of telephone receiver is given in Fig. 154, in plan (*a*) and elevation (*b*). The magnet is of a ring form *A* and is in three layers. The magnet is made of hard steel and is so magnetised that there is a *N* pole at *N* and a *S* pole at *S*, the two poles being at opposite ends of a diameter. The two soft iron pieces *C* and *D* are maintained as *N* and *S* poles by the permanent magnet, and on them are wound the coils through which the variable current from the transmitter passes. The variation in current causes variation in the pull between their pole pieces and the iron diaphragm *E*. The ebonite cover *F*, provided with a hole in the centre, is placed in contact with the ear, to enable the sound waves produced (p. 170) to be distinctly audible. The diaphragm *E* and cover *F* are supposed to be removed in Fig. 154 (*a*) to enable the magnets and coils to be seen.

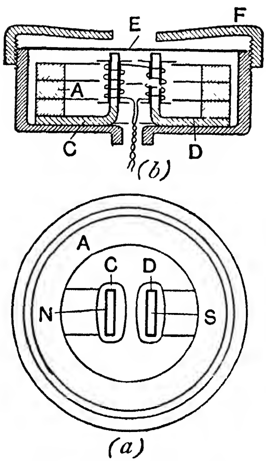

FIG. 154.—Telephone receiver.

The poles on which the coils of the receiver are wound are always kept magnetised by a hard steel permanent magnet. If this were not done the motion of the diaphragm, due to the small variations in current of the coil, would be very small and the sounds heard would be very

feeble. Owing to the permanent poles, the diaphragm is permanently magnetised, and the force between the diaphragm and the magnet is proportional to the strength of pole upon each, that is to the product of their pole strengths, or to the square of the strength of the original pole on the iron.

If now a graph is plotted connecting pole strengths of the permanent magnet, and pull between the magnet and the diaphragm, which is proportional to the square of the pole strength, it will be of the form shown in Fig. 155. It will then be seen that for a feeble pole strength, a change in value AB, due to the alteration in current, will only cause the small variation CD in the pull on the diaphragm. But if the change EF is exactly the same as AB, but corresponding to a greater pole strength, the variation in pull on the diaphragm is the quantity GH which is much larger than CD. Hence the sounds produced will be much louder in this case because the loudness of the sound depends upon the movement of the diaphragm, which in turn depends upon the **variation in pull** of the magnet upon it. This process must not, however, be pushed too far, because if the magnets are so highly magnetised that magnetic saturation is nearly reached, a given variation in the current will produce a very small change in the magnetisation.

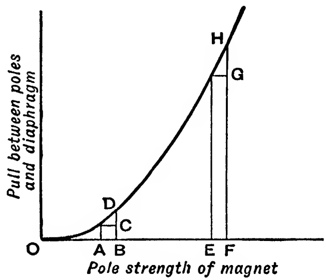

FIG. 155.—Graph showing pull on diaphragm.

Use of transformers.—It is important that the variation in current produced by the transmitter should be as large as possible. This involves as large a change of resistance in the microphone as can be attained. If

the line between the transmitting stations is very long, the resistance of the microphone can only be a small fraction of the resistance of the whole circuit, and the variations in resistance of the microphone produced by the sound waves will only be an insignificant fraction of the whole resistance. This would limit the use of the telephone to very short distances, were it not for the use of the **transformer**.

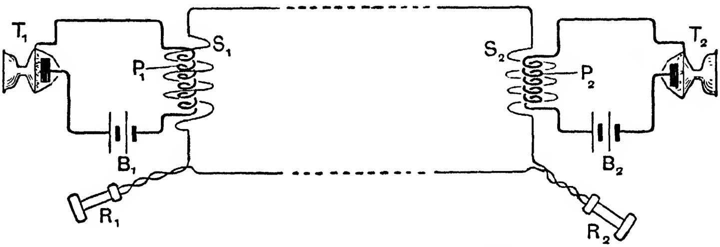

FIG. 156.—Use of transformer with the telephone.

The two coils P_1 and S_1 (Fig. 156) are the primary and secondary coils of a transformer, and any variations of current in P_1 will cause an e.m.f. and therefore current in S_1 (p. 129). P_1 is in series with the microphone transmitter T_1 and battery B_1, so that on speaking into T_1, the ordinary variations in current occur in P_1, and since P_1 is a primary coil of low resistance, the variations of current produced by the microphone will be considerable, as explained above. The secondary coil S_1 consists of many turns and the varying e.m.f. in it will therefore be great. It is in series with the line connecting the stations and with the secondary coil S_2 of the transformer at the distant station. The two receivers R_1 and R_2 are also included in this secondary circuit, and the variations of current in R_2 cause a reproduction of sound waves falling on T_1.

As the telephone sets at the two stations are alike, it can easily be seen that sound waves falling on T_2 will be reproduced at R_1. The secondary circuit of the two transformers must be complete, and a twin wire may be used to connect the stations; but in some cases a single wire is used, in conjunction with an **earth return** (p. 12).

Ringing up circuit.—In order to call the attention of a distant station, some arrangement such as an electric

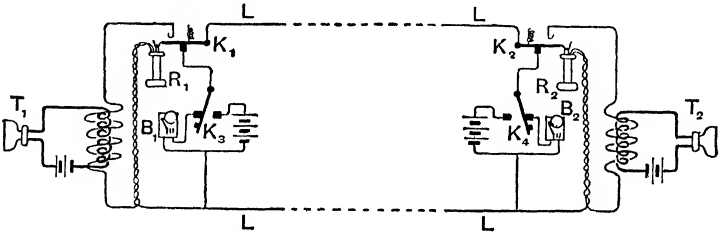

FIG. 157.—Ringing up circuit.

bell is necessary, and for ringing this bell it is necessary to switch out the microphone circuit and make use of the line connecting the two stations. Further, the circuit must be left, when not in actual use for speaking, in such a way that the bell can always be rung by the distant station. One arrangement for doing this is illustrated in Fig. 157.

The receiver R_1 is shown hanging from a hook at the end of a switch, with the transformer disconnected from the line. The switch K_1 connects the bell B_1 to the line so that if the switch K_4 is pressed at the distant station, the bell B_1 rings. At the same time if K_3 be pressed, the bell B_2 rings. If, after ringing up, the receivers R_1 and R_2 are taken from their hooks, the bell circuits are cut out and the secondary coils of the transformers are connected to the lines by the switches K_1 and K_2. On the completion of the conversation,

the receivers are hung up again on their hooks and the calling up circuits are ready as before. There is also a switch in the microphone circuit not shown in Fig. 157, which breaks the primary circuit when not in use. This switch is also actuated by hanging up the receiver on its hook and by removing it from the hook.

For the employment of great numbers of telephones on one system, **telephone exchanges** are necessary, but exchange practice is beyond the scope of this book.

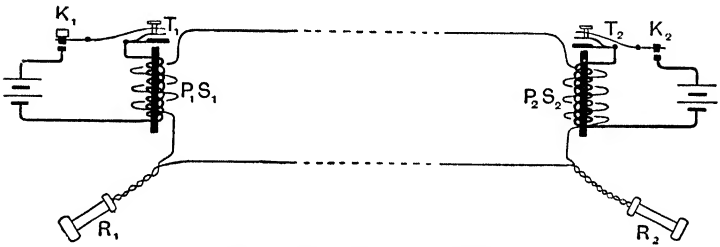

FIG. 158.—Buzzerphone circuit diagram.

The buzzerphone.—For military signalling, speech, in many cases, is not permissible; and further, the range of audibility is extended if a small induction coil is used for transmitting signals, instead of attempting to speak.

Many complicated forms of apparatus are in use, but they depend upon the principle illustrated in Fig. 158. At each station is a set consisting of the transformer, P_1 S_1 or P_2 S_2, the coils of which are wound on the same iron core. The transformer has an iron core, just like the induction coil (Fig. 130) and actuates the trembler T_1, thus constituting a buzzer similar to that of Fig. 9. The interrupted current in the primary coil P_1 causes induced e.m.f.s in the secondary coil S_1, which pass through the telephone receiver R_2 at the distant station. Thus, on depressing the key K_1, a buzz is heard in R_2,

and by pressing the key K_2 a buzz is heard in the receiver R_1. This arrangement is sometimes called the **buzzer-phone**, and on using a long or short buzz for a dash or a dot, the Morse system of signalling can be employed. A microphone is also supplied with the set so that speaking can be effected when required.

EXERCISES ON CHAPTER XIV.

1. What are sound waves ? How may they be produced ?

2. Describe the principle on which the Bell transmitter was constructed.

3. How is a variable current converted into sound waves by means of a telephone receiver ?

4. Explain why the pole pieces of a telephone receiver must be permanently magnetised.

5. Describe, with sketch, some form of telephone receiver.

6. What is the carbon microphone and what is its chief use ?

7. Describe some modern form of telephone transmitter.

8. Explain why a single circuit telephone cannot be used for considerable distances.

9. Describe the use of the transformer, explaining how it extends the use of the telephone over long distances.

10. Make a sketch of a single telephone system with transformer.

11. Describe a telephone circuit for combined calling up and speaking.

12. Make a sketch of a combined buzzer and telephone system.

ANSWERS

CHAPTER VI. p. 62.

4. 59·9 ohms.
8. 4 amperes.
9. 0 2 ampere.
10. 0·662 ampere.
13. 0·69 volt.
14. Connect in parallel a resistance of 1/999 of that of the milliammeter.
15. Connect a resistance of 988 ohms in series with the milliammeter.

CHAPTER VII. p. 76.

5. 0·81 H.P. approximately.
7. 280 amperes ; 29400 watts.

CHAPTER VIII. p. 86.

2. No. 26 tin or No. 40 copper.

CHAPTER IX. p. 101.

3. 6 ohms.

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